1. Zozan Saadallah Hussain [1], 2. Shatha Y. Ismail [2], 3. Hassaan TH. H. Thabet [3]

Northern Technical University ([1,2]), Freelance Researcher([3])
ORCID: 1. 0000-0001-8948-2277; 2. 0000-0002-6787-949X; 3. 0000-0003-4076-6978

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A Simulated Design of an Adaptable Smart Sprinkler Irrigation System using PLC Networking

***Abstract**. The paper's primary goal is to provide a simulation of an intelligent irrigation system that helps in saving money and water. The system is controlled using two Programmable Logic Controllers (PLCs) and a Human Machine Interface (HMI) which are connected via Ethernet, they are programmed to control the whole operation with the help of sensors and actuators without any interference of a human being, and the role of the operator is just to start or stop the system by switching it ON or OFF.*

***Streszczenie.** Głównym celem artykułu jest przedstawienie symulacji inteligentnego systemu nawadniania, który pomaga oszczędzać pieniądze i wodę. Sterowanie systemem odbywa się za pomocą dwóch Programowalnych Sterowników Logicznych (PLC) oraz interfejsu człowiek-maszyna (HMI), które są połączone poprzez Ethernet, są zaprogramowane tak, aby sterować całą pracą za pomocą czujników i elementów wykonawczych bez ingerencji człowieka, oraz rolą operatora jest tylko uruchomienie lub zatrzymanie systemu poprzez włączenie lub wyłączenie go. (**Symulowany projekt adaptowalnego inteligentnego systemu nawadniania zraszaczy z wykorzystaniem sieci PLC**)*

Keywords: Programmable Logic Controllers (PLCs), Pulsating Irrigation, Ethernet, Evapotranspiration, Human Machine Interface (HMI).
Słowa kluczowe: Programowalne sterowniki logiczne (PLC), nawadnianie pulsacyjne, Ethernet, ewapotranspiracja, interfejs człowiek-maszyna (HMI).

Introduction

Nowadays, water shortage is becoming one of the biggest problems in the world; because of the lack of rain, scarcity of water reservoirs and resources. It is very important to use a proper method to reduce wastage in the amount of water used in irrigation [1]. In this paper; the authors try to establish a simulation of a smart irrigation system by utilizing the techniques of the PLC and its industrial network (Ethernet) with the help of different sensors (rain, soil moisture, and temperature sensors) and the daily solar radiation (Ra) to achieve the reduction of water wastage in sprinkler irrigation as a target of their paper. Fig. 1 shows two PLCs; the first PLC (LOGO! 8) is the server and the second PLC (s7-200 smart) is the client; they are connected via Ethernet cable to establish communication between them; they are communicating via Ethernet cable through their Internet Protocol (IP) addresses.

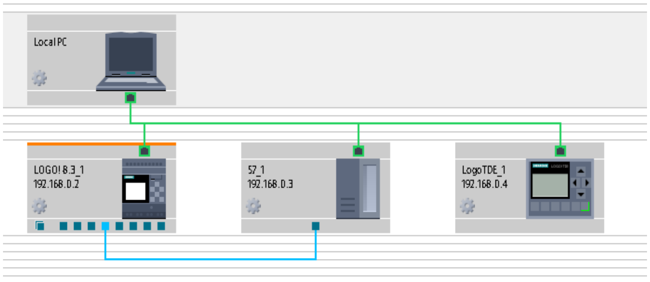

Fig.1. Main construction of the control system

A Text Display (TD) is also used as an HMI in this paper to display messages about system progress and urgent cases.

Theoretical basics

Since water is a precious natural resource; its wastage is not recommended so the amount of water needed for irrigation must be controlled according to the climate and the circumstances of the irrigated area [2]. This can be done by increasing the amount of water when the weather is hot and sunny and decreasing the quantity of water when the weather is cold and cloudy. By applying the chopping technique or DC to DC conversion [3] on the voltage supplied to the solenoid valve; the amount of water Q (L/min) that supplies water to the irrigated area could be controlled as shown in Fig. 2 and Fig. 3.

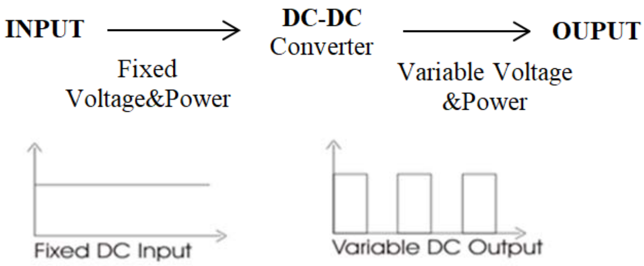

Fig.2. The chopping concept

Basically; a chopper is a power electronic device that converts a fixed DC voltage to a variable DC voltage [3]. As shown in figure (3); the average output voltage Vo can be given by:

$$V_o = \frac{1}{T}\int_0^{t_1} V_o \, dt = \frac{t_1}{T} V_s \qquad (1)$$

Where: T is the chopping period, t_1 – the ON period, $t_{1/T}$ – the duty cycle.

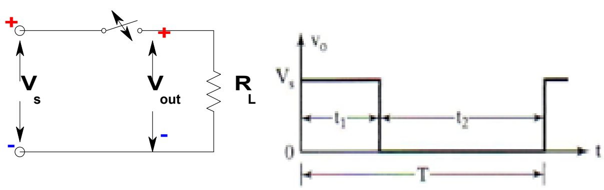

Fig.3. Basics of PWM

The duty cycle in this paper is controlled by a constant frequency operation; where the chopping period T is kept constant and the ON time period t_1 is varied. This means that the width of the pulse is only varied so this type of control is known as Pulse Width-Modulation (PWM) control [3]. Fig. 4 explains how the quantity of water is controlled by applying the PWM control. The 1st part of this figure shows full amount of water (%D = %100), the 2nd part shows the pulsated action (%D > %50), the 3rd shows (%D = %50) and the 4th shows (%D < %50). Of course, (1) means that the valve is ON (open) and (0) means that the valve OFF (closed).

T is the total period of the irrigation operation.

t_1 is the ON period of the valve.

t_2 is the OFF period of the valve.

D is the percentage duty cycle of the irrigation system.

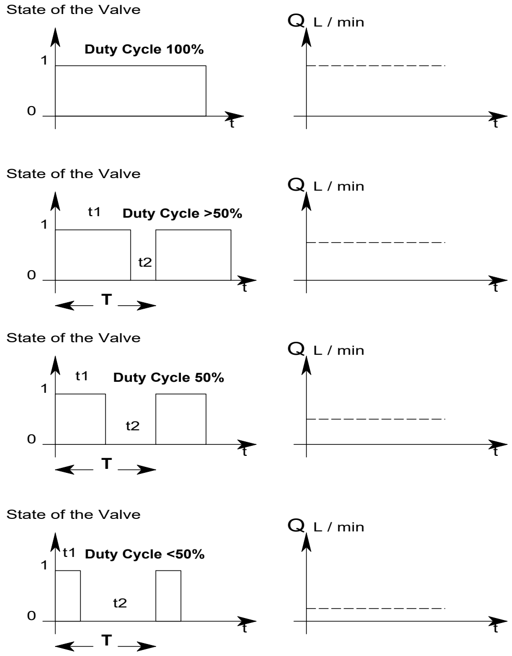

Fig.4. Principles of the timed irrigation

Hardware Task

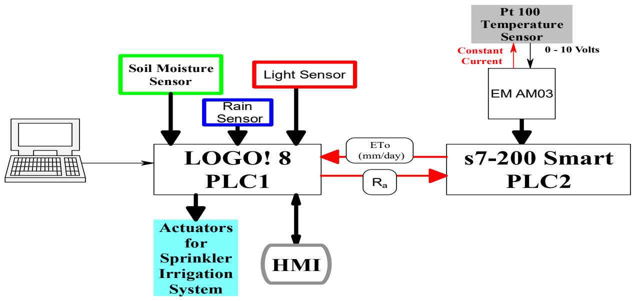

Fig.5. Block diagram of the control system

The block diagram of our control system is shown in Fig.5. It consists of:

1. LOGO!8 PLC with its software (SoftComfort V8.3) [4].
2. s7-200 Smart PLC with its software (MicroWIN V2.1 SMART) [5].
3. A PC Laptop.
4. LOGO! TDE [6].
5. Analogue Extension Module (EM AM03) [7].
6. A water pump for supplying water and a solenoid valve to control the pulses of the sprinkler irrigating system.
7. Rain sensor [8].
8. Soil moisture sensor [9].
9. Temperature sensor [10].
10. Light sensor [11].

As seen in Fig. 5, measuring and scaling the temperature by the analogue Extension Module (EM AM03) is accomplished by connecting a Pt100 temperature sensor to one of the input channels of the EM AM03. This module converts the temperature conditioned resistance changes of the Pt100 into voltage quantities, and in order to establish a linear relationship between the input temperatures and the output voltages, the analogue output channel of EM AM03 is used as a constant current source [7]. The EM AM03 sends the output voltages to the PLC to exploit them in its program. The Pt-100 Resistance Temperature Detector (RTD) [10], shown in Fig. 6 is a temperature sensor that contains a platinum resistor material with a value of 100Ω at 0^{oC} whose resistance value changes as its temperature changes. When the sensor is exposed to a heat source and provided with a constant current, scaling the voltage drop across the resistor then the temperature can be determined. It is highly accurate and stable.

Fig.6. The Pt-100 RTD

Also in Fig. 5 three other sensors can be realized:

The Rain Detector (Sensor) [8], which is used to detect the rainfall events. It is connected to the pulsated irrigation system (PLC) in order to shut it down whenever there is a rainfall for water conservation. The rain sensor module is shown in Fig. 7 and its basic working principle is like a potentiometer whose resistance varies according to the amount of water on its surface, the more water on its nickel coated lines, the lower is its resistance (closed switch) and vice versa (open switch).

Fig.7. The Rain Detctor (Sensor)

The Light Senor (LDR) [11], is used to determine the sunny, cloudy and hazy periods at day time depending on the amount of the intensity of the light falling on it. The relationship between this intensity of the light and the amount of the sensor's resistance is completely inverse, which means a very low resistance at day period (closed switch) and a very high resistance at night period (opened switch). Fig. 8 shows an outdoor Light Dependent Resistor (LDR).

Fig.8. The Light Sensor (LDR)

The Soil Moisture Sensor [9], this is a fork shaped sensor (probe) whose resistance inversely proportional to the soil moisture, which means high soil moisture will result low resistance and vice versa. This sensor contains also a high precision comparator for setting a threshold point as shown in Fig. 9.

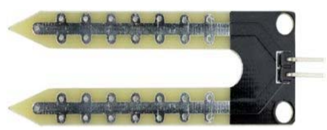

Fig.9. The Soil moisture sensor

Fig. 10 shows the schematic diagram of the control circuit Part for the smart irrigation system. It consists of PLCs, TD200, EM AM03, sensors.

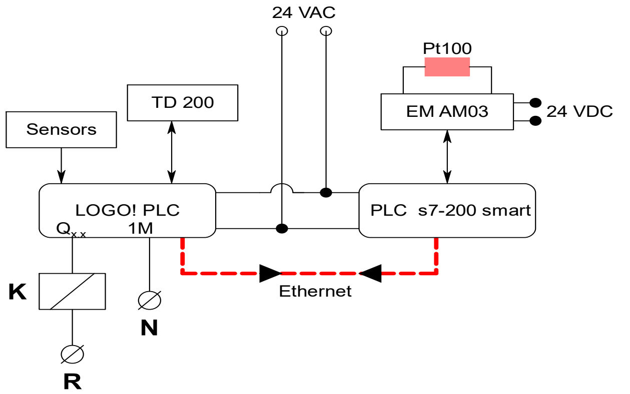

Fig.10. Schematic diagram of the smart irrigation system (control part)\

PLC s7-200 smart [5], shown in Fig. 11 is an industrial compact type PLC which continuously controls and monitors the states of its inputs and make its decisions according to a custom program to control the state of its outputs, it has an Ethernet port (RS45) so it can be connected to any network via an Ethernet cable. the main specifications of this PLC are shown in table 1.

Fig.11. PLC s7-200 smart (AC/DC/Relay)

Table 1. Specifications of PLC S7-200 Smart CPU SR30

PLC s7-200 smart	**CPU-SR30 AC/DC/Relay**
Power Supply	24 VAC
Digital Inputs	14 (24VDC)
Digital Outputs (Relay)	10 (220VAC)
Analog Inputs	2 (0-10) VDC
Analog Outputs	1 (0-10) VDC

LOGO! PLC V8 Standard [4], is an intelligent logic module used for small automation projects in industrial, commercial and residential settings. It is shown in Fig. 12 below. the main specifications of this PLC are shown in table 2.

Fig.12. LOGO! PLC V8 standard (AC/DC/Relay)

Table 2. Specifications of PLC LOGO! V8 Standard

PLC LOGO! V8	**Standard, AC/DC/Relay**
Power Supply	24 VAC
Digital Inputs	8 (24VDC)
Digital Outputs (Relay)	4 (220VAC)
Analog Inputs	4 (0-10) VDC

Extension Module (EM AM03) [7], this extension module that is shown in Fig. 13 is used here in order to supply the Pt-100 with a constant current for scaling purposes. The main specifications of this extension module are shown in table 3.

Fig.13. EM AM03

Table 3. Specifications of EM AM03

Analog Unit	**EM AM03**
Power Supply	24 VDC
Analog Inputs	2 (0-10) VDC
Analog Outputs	1 (0-10) VDC

Text Display (TD200) (HMI) [6], shown in Fig. 14 is a two line text display and an operator interface used for the s7-200 PLCs' family. It can perform the following two main important actions:

- Displays massages came from the s7-200 smart CPU.
- Allows adjustment of the program variables.

TD200 can be connected to the PLC through the TD/CPU cable. As an interactive device, the operator can change any variable set by the programmer as in our case (T_{max}, T_{min}, α, β) - online without interrupting the process.

Fig.14. TD 200

Fig. 15 shows the schematic diagram of the power circuit part for the smart irrigation system. It consists of contactors, solenoid valves, electric water pump and indication lamps. When the coil of contactor (K) is actuated by the PLC as seen in Fig. 10; the state of the pulsated irrigation system will be (ON), so the electric water pump, the solenoid valve and the green indication lamp will be operated, but the red indication lamp will be (OFF) and vice versa.

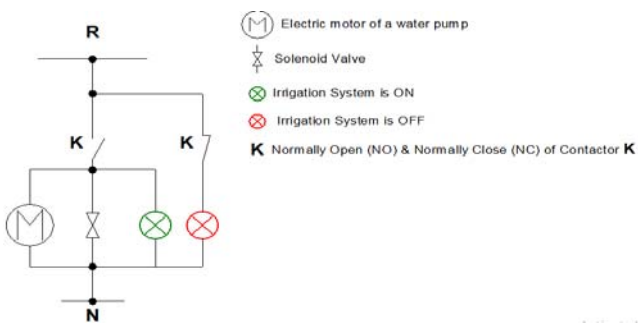

Fig.15. Schematic diagram of the smart irrigation system (power part)

The ratings of the contactor in Fig. 16 should depend on its load and the voltage power supply. The ratings of our contactor are:

- Coil voltage 220 VAC/50 Hz.
- 3NO power contacts (16 A/220 V).
- 2NO and 2NC control contacts (1A/220 v).
-

Fig.16. Contactor

The ratings of the solenoid valve in Fig. 17 are: 1/2" Brass. Electric solenoid valve with coil voltage 220V AC, Normally Closed, used for water applications of 30-50 psi.

Fig.17. Solenoid valve

The ratings of an external centrifugal water pump shown in Fig. 18 are: (1/2-1)Hp, single phase induction motor, 220VAC/50 Hz, IP 44.

Fig.18. Electric water pump

Software Design

Many methods [12, 13, 15] were used to calculate the daily evapotranspiration to establish the amount of water needed by the crops; one of those methods is the Jensen and Haise method which was derived for the drier parts of the United States [12], it could be used in Iraq also, the mathematical model of this method is shown in equation (2):

$$ET_0 = \alpha \times \frac{T.Ra}{2450} + \beta \quad (2)$$

where: ET_o – Evapotranspiration (mm/day), T – Measured ambient temperature in (°C) at height 1.5 m above ground, R_a -Extraterrestrial Solar Radiation (Mj m^{-2} day^{-1}), α - 0.025 Constant #1 for the tested area, β - 0.08 Constant #2 for the tested area.

Table 4. The average monthly values of the extraterrestrial solar radiation (Ra)

Month	R_a
January	8.95
February	12.09
March	16.30
April	19.84
May	23.91
June	27.60
July	26.48
August	24.39
September	19.83
October	13.67
November	10.12
December	9.0

The average monthly values of the extraterrestrial solar radiation (Mj m^{-2} day^{-1}) for Mosul/Iraq (Lat. 36.32° & Long. 43.15°) [12, 14]; are shown in table 4:

The values of the solar radiation in the table above are stored in LOGO!8 (PLC1). At the beginning of each month; its related value of Ra will be send to s7-200 smart (PLC2) via Ethernet for calculation purposes.

Fig. 19 shows the flowchart of the main program of PLC2; this PLC receives the hourly measured temperature degrees (T) from the temperature sensor [10,16] as electrical signals by its analog input unit, converts them to scaling units and stores them. It also receives Ra value of the month from PLC1 via Ethernet cable; these two parameters with the values of α and β, as shown in Fig. 19; are used by equation (2) to calculate the value of ET_o (Evapotranspiration) and then send this value to PLC1 via Ethernet cable.

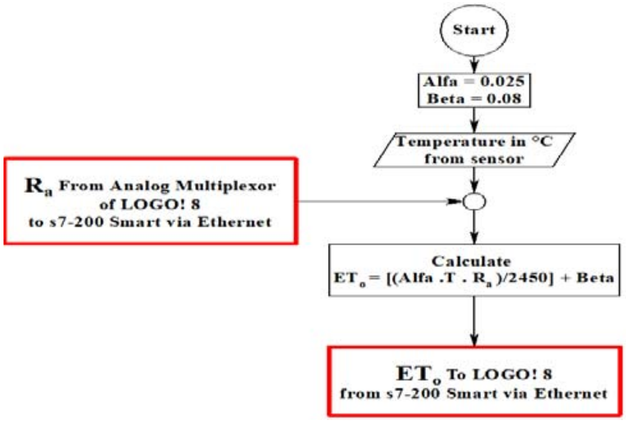

Fig.19. Flowchart of the s7-200 smart PLC program

Fig. 20 displays a section of the main program that allows PLC2 to receive the analog values of the ambient temperature from the temperature sensor (Pt-100), scale them to voltage values (0V-10V) and store them in the PLC memory to use them in equation (2).

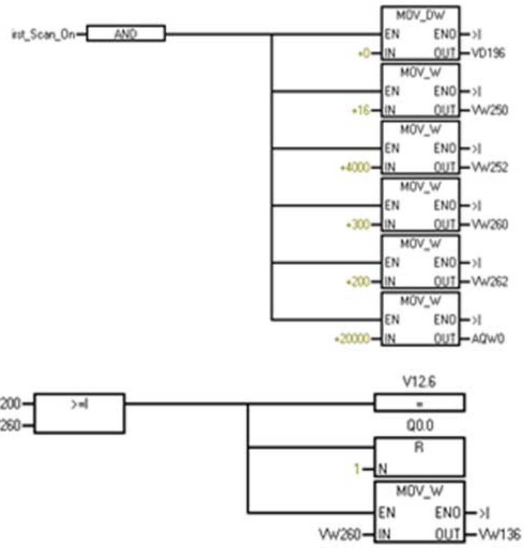

Fig.20. A section of measuring and scaling subroutine

PLC1 is the server; its algorithm flowchart is shown in Fig.22, which is responsible of the following tasks:

1. Sets the duration of the ON period of the irrigation system by the following software functions [4]:
   - The astronomical clock that determines day or night [4,16].

- The yearly timer to determine the value of Ra for each month of the year.
- The weekly timer which sets the daily irrigation periods.

2. Switches the irrigation system ON/OFF in accordance to the information from the rain sensor.
3. Controls the irrigating system by the soil moisture sensor with the cooperation of the rain sensor and the light sensor by increasing or decreasing the duration of the ON period of the irrigation system in accordance to the moisture of the soil (at night period) and with the quantity of light (at day period).
4. Sends information (stored Ra values) to PLC2 (client). Fig. 21 shows a section of the program of PLC1 which selects the suitable value of Ra by an analog multiplexer (Analog Mux) function which is available in SoftComfort V8.3 and send it to PLC2 via the Ethernet cable by the function (NAQ) [4, 17].

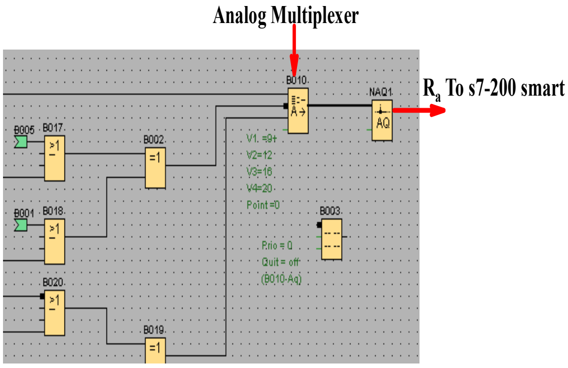

Fig.21. A section of PLC1 main program

5. Receives information (calculated ET_o values) from PLC2.
6. Starts the irrigating system and controls its ON and OFF periods according to the information received.
7. Displays massages on the HMI (TD) to show system progress and announce urgent cases.
8.

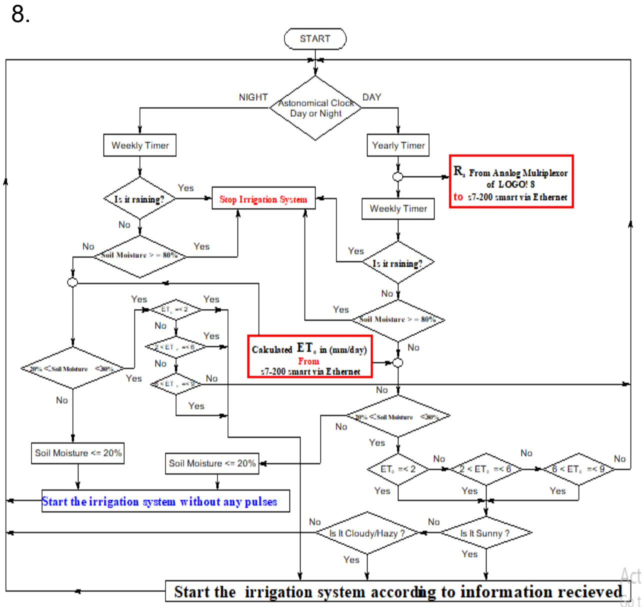

Fig.22. Flowchart of the LOGO!8 PLC program

Results

Fig. 23 describe the main parts of the simulated irrigation system in the laboratory as:

1. PLC1 (The Server).
2. PLC2 (The Client), EM AM03.
3. HMI (TD200).
4. The motor of the water pump.
5. The solenoid valve.
6. The operation of the system as pulses on the oscilloscope.

Fig.23. Simulated practical irrigation system

In Fig. 24 (a, b); it could be noticed that the actuators (solenoid valve and water pump) are controlled according to the calculated values of (ETo), the sensed values of the soil moisture (at night period) and with the two added sensed values of the rain presence and the quantity of light (at day period), the PLC will take its decision which means that when ETo is equal or less than, say, for example, 2mm/day (which means that the temperature is low) then the time of the ON period (opening the solenoid valve and operating the water pump) is decreased as seen in Fig. 24(a).

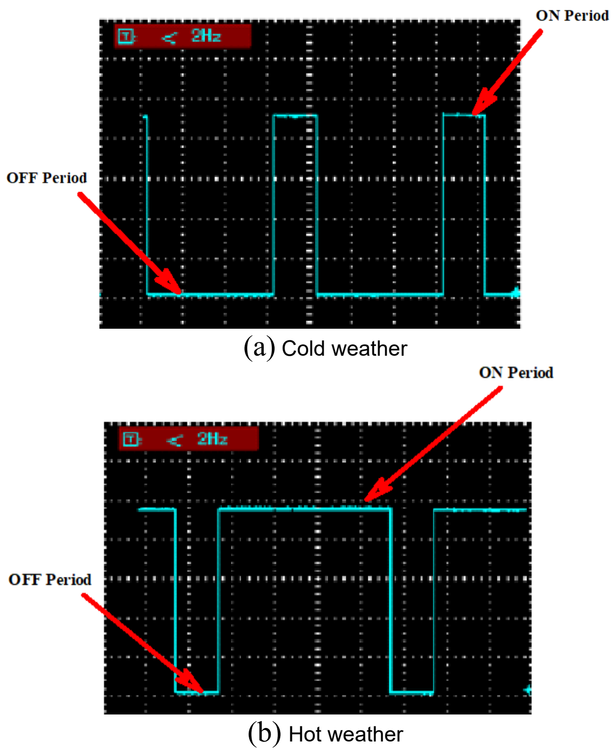

Fig.24 (a, b).

The control system increases the time of the opening period of the solenoid valve and the ON period of the water pump and decreases the time of the closing period of the solenoid valve and the OFF period of the water pump which yields to the increasing values of the calculated (ETo) as the temperature rises; as shown in Fig. 25(b). The following figures were recorded by an oscilloscope from the output of PLC1. The Soil moisture sensor, the rain sensor and the light sensor interfere with the decision taken by PLC1 in accordance with the signals received from them byincreasing the ON period and decreasing the OFF period and vice versa.

Conclusion

The adaptable smart pulsating Irrigation system that is designed and simulated in this research seems to be very efficient; economical and useful in irrigating crops around the year if implemented practically by farmers because it monitors and controls all the activities of the pulsating irrigation system efficiently. Using this system; one can save water; manpower and electrical power consumption. An inexpensive PLC system is used to make hourly measurements of air temperature at a height of 1.5m; these measurements are stored and used by the system to calculate the daily ETo. The algorithm uses these values in addition to the signals from other sensors to determine the timing of the ON and OFF periods of the pulsating system to decrease the wastage of water in the irrigation procedure. Frankly, this system is designed and simulated as a general case of irrigation; so it needs an agronomist to implement it practically and efficiently. He can manipulate the system parameters such as the astronomical clock or the yearly and weekly timers to supply the sufficient amounts of water needed for each type of crops without any wastage.

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Authors: Zozan Saadallah Hussain, e-mail: zozan.technic@ntu.edu.iq; Shatha Y. Ismail, e-mail: shathayousif61@ntu.edu.iq; Hassaan TH. H. Thabet, e-mail: engineer.h.thabet@gmail.com.
The correspondence e-mail: zozan.technic@ntu.edu.iq

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