

Design and Simulation of an Adaptable Pulsating Irrigation System Using Programmable Logic Controller Unit

Abstract. Due to the scarcity of water on the globe today, it is considered as a valuable natural resource. This requires intensive and applied research to preserve it, and this, in turn, requires the design of smart irrigation systems that use water according to the actual needs of plants and with the least possible waste. Currently, plants irrigation all over the world consumes most of the freshwater that should be used in other more important areas. The commercial irrigation water controllers that are widely used in the world do not fulfill their intended purpose of saving the amount of irrigation water. The development and lower price of PLC have made it possible to use them as standalone controllers for smart and economical irrigation. In this paper a PLC type (s7-200) was used to control daily pulsed irrigation amounts according to actual transpiration ETo, using the Hargreaves-Samani method. Once ETo is calculated by the PLC, it begins to manage the timing of the irrigation system pulses as per the commands given by its program depending on the calculated values of the ETo.

Streszczenie. Ze względu na niedostatek wody na świecie jest dziś uważany za cenny zasób naturalny. Obecnie nawadnianie roślin na całym świecie pochłania większość słodkiej wody, która powinna zostać wykorzystana w innych, ważniejszych obszarach. Komercyjne sterowniki wody do nawadniania, które są szeroko stosowane na świecie, nie spełniają swojego zamierzonego celu, jakim jest oszczędzanie ilości wody do nawadniania. Rozwój i niższa cena programowalnych sterowników logicznych (PLC) umożliwiły wykorzystanie ich jako samodzielnych sterowników do inteligentnego i ekonomicznego nawadniania. W tej pracy zastosowano PLC typu (s7-200) do kontroli dziennych pulsacyjnych ilości irygacji zgodnie z rzeczywistą transpiracją (ETo), przy użyciu metody Hargreaves-Samani. Po obliczeniu ETo przez PLC, zaczyna on zarządzać synchronizacją impulsów systemu irygacyjnego zgodnie z poleceniami wydanymi przez jego program w zależności od obliczonych wartości ETo. (Projektowanie i symulacja adaptowalnego pulsacyjnego systemu nawadniania z wykorzystaniem programowalnego sterownika logicznego)

Keywords: Evapotranspiration, Programmable Logic Controllers (PLCs), Pulsating Irrigation .

Słowa kluczowe: nawadnianie, system pulsacyjny, PLC, irygacja pulsacyjna.

Introduction

Large quantities of irrigation fresh water, estimated by more than thousands of cubic meters, are wasted by governments around the world to maintain gardens and green spaces in cities and fields and other problems on the power systems [1,2,3]. Where reliance is on factory programmed control devices to operate irrigation systems [4,5] and these devices are usually programmed for drought conditions and higher temperatures of the irrigation area to satisfy the plant's need for water, so they waste a lot of water on cold or cloudy days. This paper attempts to develop an intelligent, automatic pulsed irrigation system that uses easy climate criteria to adjust daily irrigation amounts according to the needs of any plant due to the climatic conditions in which this plant is located. Temperature and total sun radiation are criteria measured directly by the PLC unit to adapt the timing of the pulsated irrigation, saving great amounts of waters without using expensive sensors and costly weather stations. A PLC type s7-200 from Siemens, a Human Machine Interface (HMI), an analog extension module (EM) [6], a temperature sensor type Pt100 [7] and an inexpensive system for measuring solar radiation and applications of solar energy [8,9,10] were used in this simulation.

Also included in the design of a Proportional-Integral (PI) controller that employs PLC systems to control the temperature of water heated by oil-fired heaters, which are frequently used in Iraq [11]. The PI controller [12] is a feedback control loop that calculates a control system's error signal by taking the difference between the system's output and the set point determined by the operator. Some previous papers demonstrated the tuning procedures of the PI controller [13].

Hardware Task

The block diagram of our simulated control system is shown in figure (1). It consists of:

- 1- s7-200 PLC with CPU 224 [6].
- 2- Human Machine Interface (HMI) mentioned as TD200 [6].
- 3- Analog extension module EM235 which has 2 input analog channels and 1 output analog channel [6].
- 4- Temperature sensor Pt100 [7].
- 5- Solar tracking system for measuring the daily radiation in an inexpensive way [8], (the authors didn't use a PYRANOMETER to measure solar radiation in this work because it wasn't available and too expensive).
- 6- A water pump for supplying water and a solenoid valve to control the pulses of the irrigation system.

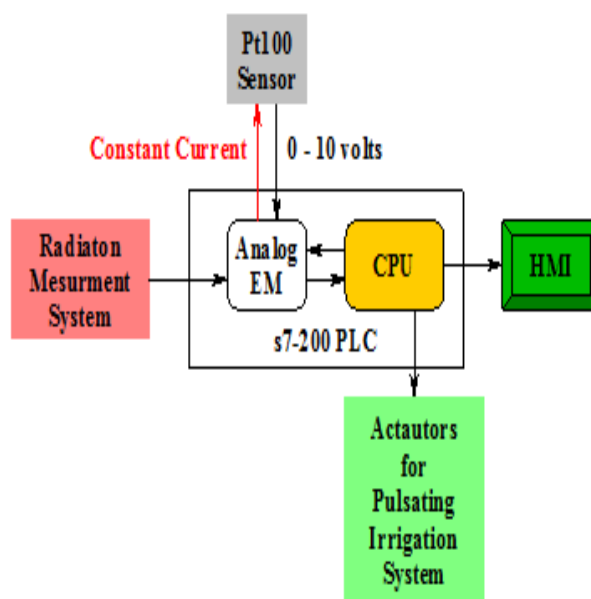


Fig.1. Block diagram of the control system

The schematic diagram of the equivalent circuit of the analog extension module (Analog EM) used in this paper is shown in figure (2). The output channel of the analog EM provides the Pt100 sensor with a constant DC current (Current Source) in order to change the characteristics of its resistance into a voltage potential difference (0–10 volts) that varies with the variation of ambient temperatures. The input channel of the analog EM, which is connected in parallel with the circuit, operates as a voltmeter because of its high internal resistance (more than 10MΩ) [6].

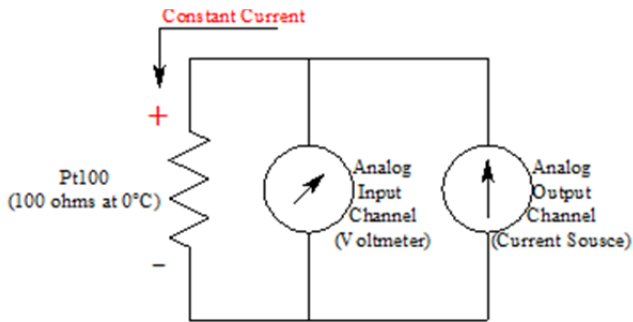


Fig. 2. Equivalent circuit of the analog EM

Software Design

The Hargreaves-Samani equation [14,15] is chosen to be implemented and simulated in this research, it can be expressed as:

$$(1) \quad ET_0 = \alpha (T + 17.78)(T_{max} - T_{min})0.5 \cdot R_a$$

Where ET_0 - is reference Evapotranspiration {mm/day}, T - is average air temperature at 1.5 m height {°C}, T_{max} - is maximum air temperature {°C}, T_{min} is minimum air temperature {°C}, R_a - is extraterrestrial radiation {MJ. m⁻².day⁻¹} and α - is calibration constant which is (0.0023) for the study area [13].

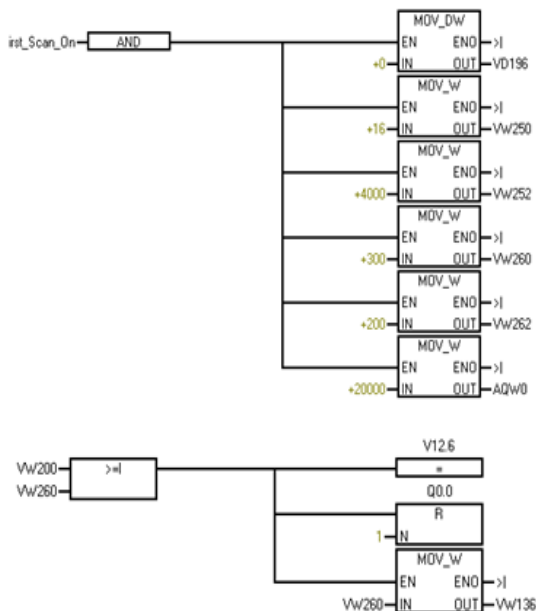


Fig.3. A section of "TEMPERATURE" subroutine

The PLC was programmed to measure the ambient temperature (T) and monitor its specified limits (T_{max} & T_{min}) by using the analog extension module EM 235 and the temperature sensor Pt100. The daily solar radiation R_a is measured by the radiation measurement system mentioned

above [7] and α is a constant. The square root function is carried out directly because it is available in the software (STEP 7-MicroWIN V4.0) used in this work [6]. The software calculates the value of ET_0 to the 1st decimal point and writes the result in the embedded variable of a message, which is read out with a TD 200 operator interface. In the initialization part of the program, the operator must enter high and low limits of the temperature, so the program displays a warning message by means of the TD 200 if the measured temperature leaves the selected range.

Figure (3); shows a section named as "TEMPERATURE" subroutine - for calculating ET_0 - which belongs to the main control program of s7-200 PLC [16].

Figure (4), shows the flowchart of the first part of the designed control program, which is a subroutine called "TEMPERATURE". It consists of two parts, the first part clears, sets and initializes the whole analog and digital variables in the first scan cycle of the PLC. The second part of the flowchart measures the ambient temperature and displays it on the HMI unit; it also compares this temperature with the max/min temperature settings and displays a warning message on the HMI unit if it exceeds those settings.

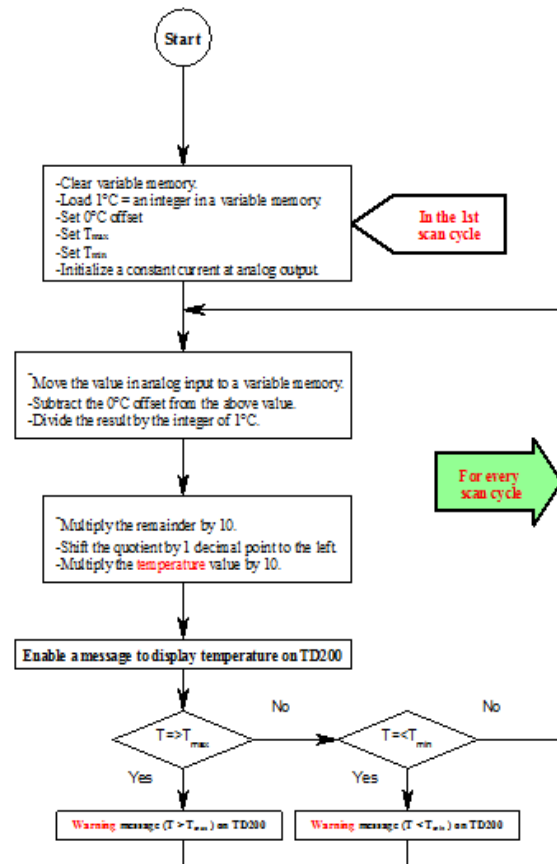


Fig.4. Flowchart of the temperature measurement & display design

Figure (5) in above, shows the flowchart of the second part of the designed control program, which contains three subroutines (#1, #2 & #3). These subroutines configure the timing of the pulses of the irrigation system according to the daily measured temperature in (°C), sun radiation in (MJ.m⁻².day⁻¹) and finally the calculated ET_0 in (mm/day); so the ON period of the actuators (solenoid valve and water pump) is increased and their OFF period is reduced when the value of the calculated ET_0 is high which means hot weather and vice versa.

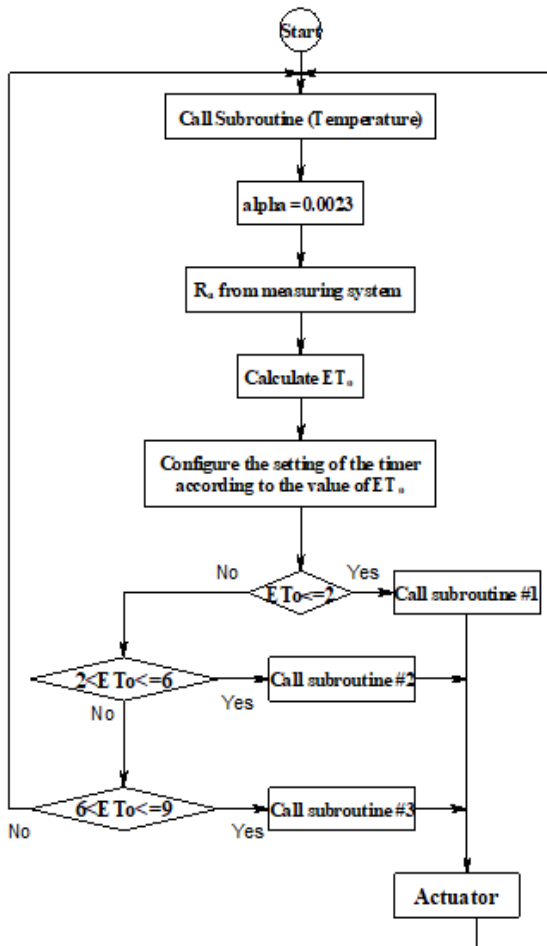


Fig.5. Flowchart of timing configuring design

Two sections of the subroutines (configure #1 and configure #3) are shown in figure (6); the calculated value of $E T_o$ is compared with the reference values of $E T_o$; when the comparison is true; the compare instruction in the software turns on the output to operate the desired timing circuit.

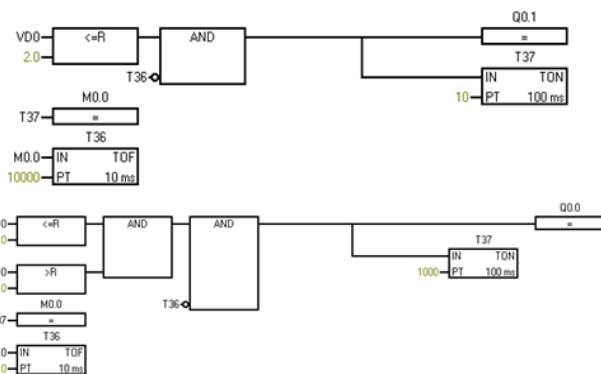


Fig. 6. Sections of "CONFIGURE" subroutines (#1 & #3)

Results

In figure (7), it could be noticed that the actuators (solenoid valve and water pump) are controlled according to the calculated value of ($E T_o$), when $E T_o$ is equal or less than, say, 2mm/day (which means that the temperature is low) then the period of opening the solenoid valve and operating the water pump is decreased as seen in figure (7-a). The control system increases this period as the temperature rises which yields to increasing the values of

the calculated ($E T_o$) as shown in figure (7-b). The following figures were recorded by an oscilloscope from the output of the PLC.

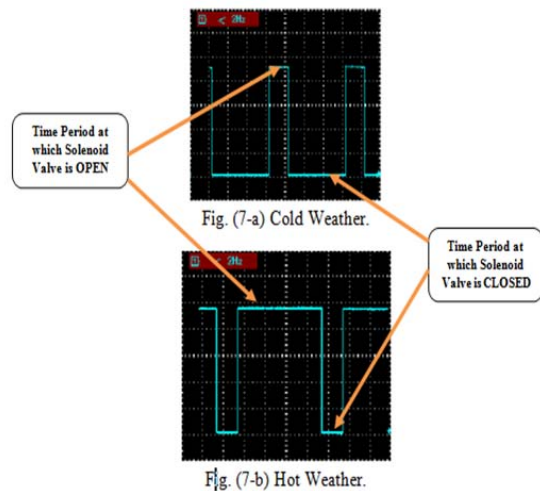


Figure 7. Solenoid valve and water pump

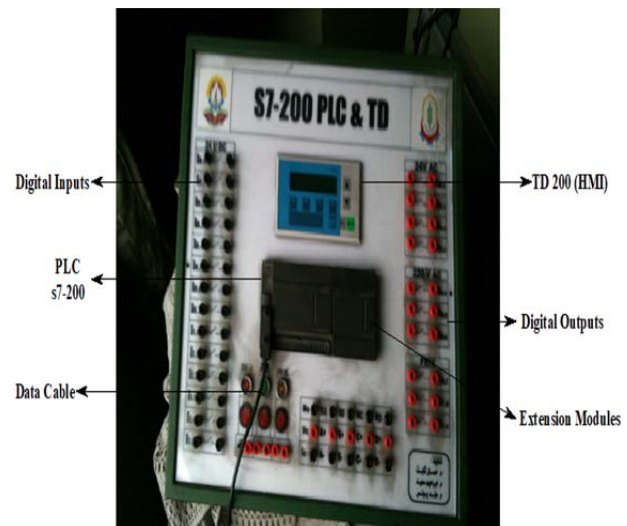


Fig. 8. Controller Unit

The controller unit shown in figure (8) is constructed by the authors as a laboratory tool; it consists of the following components:

1. PLC (s7-200)
2. HMI (TD 200)
3. Data Cable for downloading the control program from the PC to the PLC and vice versa.
4. Input ports.
5. Output ports.
6. Analog extension module (EM 235).

Conclusion

Improving irrigation efficiency and promoting water conservation requires the use of smart and modern technologies to control water irrigation processes. The aim of this paper is to increase the efficiency of the irrigation process by reducing the wastage of irrigation water to a minimum by using a smart control system based on PLC with the help of the Pt100 temperature sensor and the solar radiation measurement system, which is a simple and inexpensive system to make hourly measurements of solar radiation and air temperature at a height of 1.5 meters. The measured temperature and solar radiation measured by the PLC were used to calculate the daily Evapotranspiration

from the tested area to determine the timing of the turning ON and OFF pulses of the irrigation system. The PLC-based pulsating irrigation system offers better advantages than the conventional system, as it adapts to the environmental conditions surrounding the test area, thus increasing the efficiency of the irrigation system by minimizing the wastage of water. For future studies, our adaptive system needs a rain detector to be smarter and make the necessary changes to the irrigation schedule.

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