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Smart irrigation system using PLC, SCADA, and fuzzy control

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Abstract: This paper describes the design of smart irrigation control system for a 20-acre farm in Alexandria, Egypt, based on a Graphical User Interface GUI, Supervisory Control and Data Acquisition systems SCADA, Programmable Logic Control PLC, Fuzzy Logic Control FLC, and sensors. A SCADA system with a local Human Machine Interface HMI screen, and remote control through a VPN connection is applied to monitor and regulate the field sensors. There are various agricultural crops on this farm which are affected by the environmental parameters. The measured input parameters are soil moisture, wind speed, pressure, temperature, humidity, rain fall, and soil conductivity. The measured data are extracted from the sensors. The output is then carried out based on the applied PLC, SCADA, and fuzzy control which are designed and implemented to make a decision about the suitable operational irrigation pumps can be used. The comparison between the total daily power consumption per day for the traditional irrigation system which is 352 KWh/day, and the total daily power consumption per day for the smart control irrigation system which is 242 KWh/day, resulting the reduction rate in power and cost is 31.25%. PLC, SCADA, and fuzzy control ensure long-term water conservation in agriculture and reduction in the power consumption.

Keywords: *Artificial intelligent, Control system, Environmental parameters, Fuzzy control, Irrigation system, SCADA, PLC, Smart control.*

1. Introduction

Water usage annually is a challenge, particularly for the agriculture sector, which has been reported to be in crisis. Water conservation in agriculture has grown increasingly important. PLC, SCADA systems, and fuzzy control are regarded as intelligent controls for the regulation of irrigation systems. The minimum and maximum humidity readings from the sensors were used for controlling the watering of different kinds of plants, requiring the use of a PLC and SCADA system that determined humidity for each field [1]. Measurement and control for cultivation based on temperature, humidity sensor, soil moisture, and light intensity, which resulted in a saving in power consumption compared to the traditional system based on PLC and SCADA to regulate irrigation, were utilized [2]. The implementation of a Wi-Fi smart wireless sensor network for irrigation was conducted [3], [4]. In agriculture, smart irrigation control systems based on the Internet of Things (IoT) and Raspberry Pi technology were introduced based on data analysis collected from sensors that measured temperature, humidity, and soil moisture [5]. A smart irrigation system based on the global system for mobile communication (GSM) to assist farmers in watering their farms. This system sends out acknowledgement signals describing the status of the task, including the soil's humidity level, the ambient temperature, and the motor's condition in relation to the main power source or solar power.

The motor status outputs are produced by a fuzzy logic controller, which also computes the input parameters such as soil moisture, temperature, and humidity [6], [7]. PLC/SCADA systems were introduced in numerous studies to monitor and control a wide range of industries. The building of a multi-stage flash brine recirculation BR desalination plant with a large number of inputs and output signals based on eight main cycles: the sea water cycle, the brine recirculation cycle, the brine heater cycle, the distillation cycle, the brine blowdown cycle, the steam cycle, the condensate cycle, and the

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pressure reduction cycle controlled by PLC and SCADA systems was presented [8]. In an oil refinery process, PLC and SCADA systems were used to monitor and control four primary units: a unit for storing and pretreating crude oil, a unit for distilling crude oil, and a unit for storing and dispatching products. diesel, naphtha, petrol, kerosene, and liquefied petroleum gas (LPG) [9]. One of the most popular industrial systems was the steam boiler, which has several phases of operation that go into converting a manually controlled boiler to a fully automated one based on control by using a PLC/SCADA system [10]. Another study presented machine learning ML classifiers in conjunction with PLC and HMI to forecast and autonomously manage petroleum product terminals depending on their concentrations [11], [12]. Enhancing the identification and pattern recognition of individual gases with low-cost gas sensors based on PLC Step 7-200 was used to monitor and control the gas detector system to identify various gases as well as track and measure gas pollution emissions [13]. The detection of harmful gases such as high concentrations of carbon monoxide CO, methane CH_4, and carbon dioxide CO_2 in the air, which cause environmental pollution, was analyzed and presented [14]–[17]. Fuzzy logic was used to control the irrigation system based on a group of membership functions for inputs and output variables. Three types of membership functions—triangular membership function, trapezoidal membership function, and bell-shaped membership function—were analyzed [18], [19].An artificial intelligence technique based on fuzzy logic was used in several studies to control and predict the irrigation time for plants, which was necessary for the field of agriculture[20]. An OPC server supported the agents via the local area network LAN and the human machine interface HMI was implemented in a multi-agent system based on irrigation schedule agents, weather agents, plant watering agents, and monitoring agents [21]. It has been demonstrated that artificial intelligence models, in particular fuzzy inference systems (FIS), were applied for evaluating groundwater quality in complex aquifers. Fuzzy set theory is applied to groundwater-quality-related decision-making in agricultural production based on experimental data that is used to generate a number of new, generalized, rule-based water quality evaluations [22]. An intelligent irrigation control system for the automated management of water pumps in greenhouses and farms by considering the weather and soil moisture based on fuzzy logic, which helped the user avoid overwatering and underwatering the crop while also saving water and electricity, was recognized [23]. Electronic circuits were used to encapsulate the climate sensors with Arduino and a Simulink model to interface the system as a whole. The Simulink model used the data from these sensors to regulate the water pump's speed [24]. A fuzzy modelling technique was applied using data from an agronomic experiment. Soil water tension and salinity levels in the water were the three fuzzy sets that made up the system input variables based on fuzzy rules. The biometric and productivity analysis's output variables—plant height, stem diameter, leaf area, green biomass, dry weight, number of fruits, average fruit weight, and percentage of disabled fruits—were defined [25]. A fuzzy logic controller based on the Mamdani method was built on the Node MCU ESP8266 board mounted with a DHT22, and soil moisture, temperature, and water content in the soil as input variables to get the suitable irrigation time were introduced [26]. Another research investigation evaluated the relationship between the wages of workers and their working hours in the industry, using Zigbee and RFID transmitters and receivers for monitoring human activity and mobility within farms and factories [27], [28].

2. Materials and Methods

The objective of this paper is to design and implement an autonomous smart irrigation system using PLC, SCADA system, and fuzzy control system. The automatic irrigation control system is divided into two parts that use measurements from sensors to determine the number of pumps required to operate:

2.1 Part 1: PLC and SCADA System Control

The collected data, such as humidity, soil moisture, soil conductivity (EC), rain fall, wind speed, and pressure, are based on different types of sensors as input variables to the PLC and SCADA systems. The aim is to use the input data from the several types of field sensors to monitor and control the irrigation process according to the system settings, which can be adjusted by the operator using the HMI screen.

Figure 1 shows the flow chart of the automatic irrigation control system based on PLC and SCADA control.

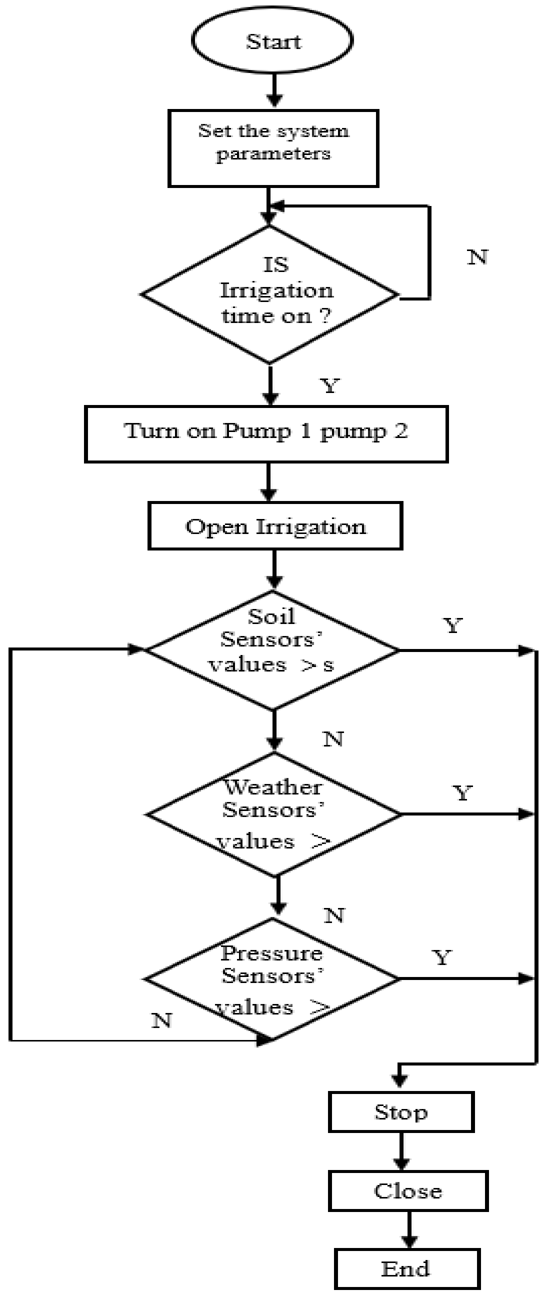

Figure 1.
The flow chart of the automatic irrigation system.

2.1.1. The SCADA / HMI System

The SCADA system, which is based on the PLC, is intended to monitor and regulate the agricultural field in order to minimise human tasks, water scarcity, and the increased need for skilled farmers to do various irrigation activities. The most important parts of the SCADA system are the master station, remote terminal unit RTU, programmable logic unit PLC, intelligent electronic devices (analogue and digital cards), and sensors. This allows the irrigation control system to be automated without the need for human intervention. The PLC is used to gather data based on sensors, implement functions like logic, sequencing, and timing, and regulate different types of machine processes, while the SCADA system, which is based on the human machine interface HMI, is used to monitor the entire process. The design and implementation of a PLC and SCADA system to control the automatic irrigation system for a 20-acre farm in Alexandria, Egypt, as depicted in figure 2, There are various agricultural crop varieties on this farm. A graphic user interface GUI is used in the design of a smart irrigation control system that uses PLC controllers to facilitate monitoring and control of the irrigation process.

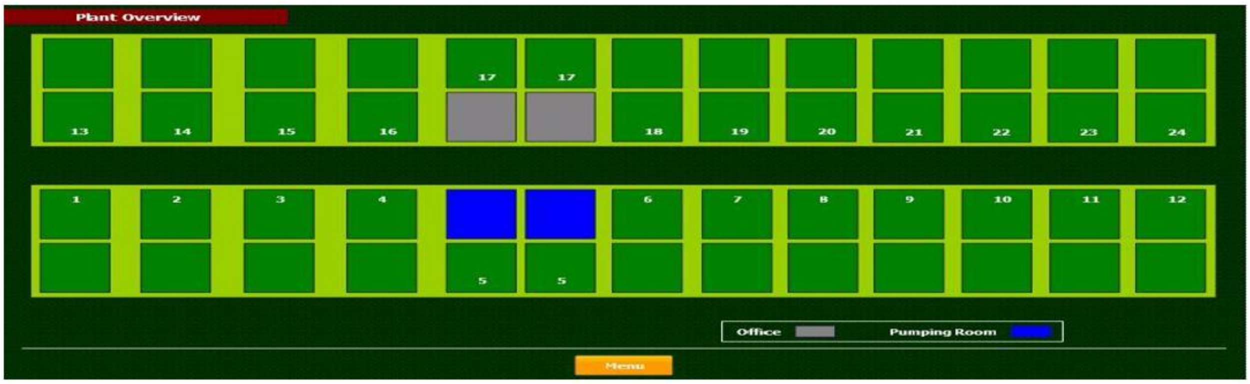

Figure 2.
The farm before implementing the automatic irrigation control system.

In order to collect data from the farm, the irrigation control system is built using a variety of sensors, including pressure and level transmitters, wind speed, rainfall, temperature, humidity, soil moisture, and soil conductivity (EC). Table 1 shows the lists of specifications for the components of the control system.

Table 1.
Control system specifications.

S. N.	Type	Specifications
1	Siemens PLC Series no. S7-1200 (Main PLC) Model no.: 1214C dc/dc/dc [29]	Power supply: 24vdc Digital inputs: 14 No.s , DC type Digital outputs: 10 No.s , DC type Analog inputs: 2 No.s , With range 0 to 10 vdc Communication port (s): 1 Ethernet port.
2	Schneider PLC Series No. M221 (Secondary PLC) Model no.: TM221CE24T [30]	Power supply: 24vdc Digital inputs: 14 No.s , DC type Digital outputs: 10 No.s , DC type Analog inputs: 2 No.s , With range 0 to 10 vdc Communication port (s): 1 Ethernet port, 1 Serial port.
3	Siemens HMI touch screen Model no.: KTP1200 Basic [31]	Power supply: 24 vdc Size: 12 inches. Communication port (s): 1 Ethernet port
4	Siemens digital input module Series no.: SM1221 Part no.: 6ES7221-1BH32-0XB0 [29]	No. of signals: 16 digital inputs 24 vdc
5	Siemens digital output module Series no.: SM1222	No. of signals: 16 digital outputs 24vdc

	Part no.:6ES7222-1BH32-0XB0 [29]	
6	Siemens analog input module Series no.: SM1231 Part no.: 6ES7231-4HF32-0XB0 [29]	No. of signals: 8 analog inputs Input range: 4-20 mA / 0- 10 vdc
7	Schneider analog input module Model no.: TM3AI8 [30]	No. of signals: 8 analog inputs Input range: 4-20 mA / 0-10 vdc
8	Pressure transmitter [32]	Power supply: 24 VDC M. range: 0 ~ 10 bar Output: 0 to 10 VDC
9	Level transmitter [33]	Power supply: 24 VDC M. range: 0 ~ 1 bar Output: 0 to 10 VDC
10	Soil moisture [34]	Power supply: 24 VDC M. range: 0 ~ 100 % Output: 0 to 10 VDC
11	Soil EC [34]	Power supply: 24 VDC M. range: 0 ~ 1000 µS/cm Output: 0 to 10 VDC
12	Air temperature [34]	Power supply: 24 VDC M. range: 0 ~ 100 °C Output: Modbus RTU
13	Air humidity [34]	Power supply: 24 VDC M. Range: 0 ~ 100 % Output: Modbus RTU
14	Atmospheric pressure [33]	Power supply: 24 VDC M. Unit: hPa Output: Modbus RTU
15	Wind speed [33]	Power supply: 24 VDC M. Unit: m/s Output: Modbus RTU
16	Wind direction [33]	Power Supply: 24 VDC M. Range: 0 ~ 360 Degree Output: Modbus RTU
17	Rain fall [33]	Power Supply: 24 VDC M. Unit: mm Output: Modbus RTU

2.1.2. GUI Design of the HMI Screen

The HMI screen with six pages is designed to monitor and control the irrigation process to achieve fully automated smart irrigation control, which includes:

2.1.2.1. Main Menu HMI Screen

It is designed to help the operator navigate among the different screens of the system, as shown in figure 3.

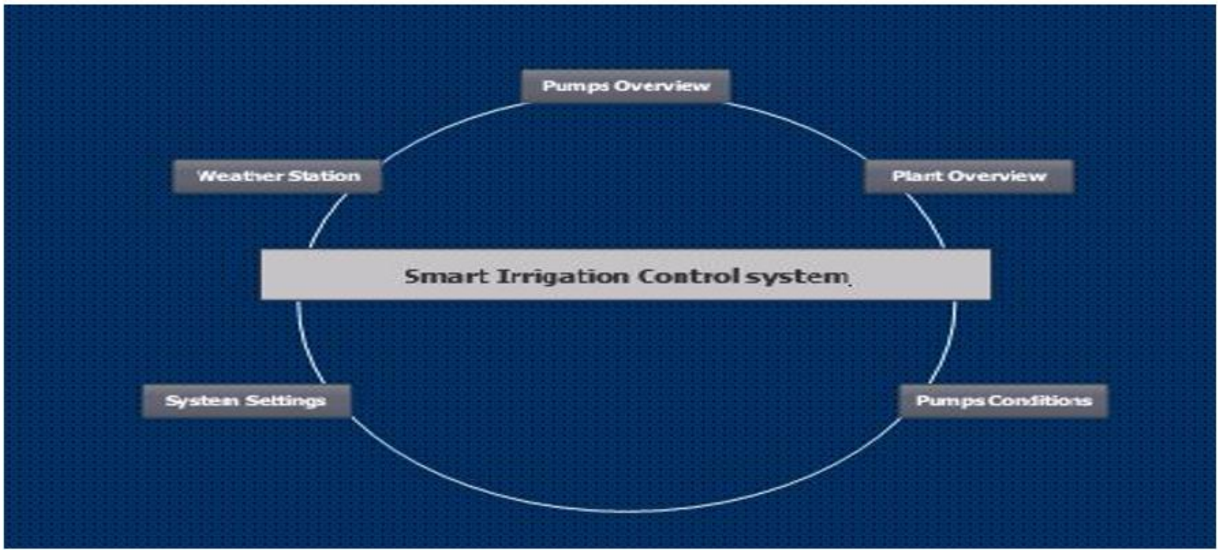

Figure 3.
The main menu of SCADA system.

2.1.2.2. Pumps Overview HMI Screen

It is designed to monitor and control the operation of the main four irrigation pumps, pre-pump water level transmitters, pressure transmitters, and filters, as shown in figure 4.

The screen includes:

- Operation status (run/stop) for all pumps.
- Pumps availability.
- Filters availability
- Discharge pressure values before and after filters.
- Analogue and digital indications for the fresh water storage level and volume.
- Manual control for the pumps
- Manual control for the preparation of valves

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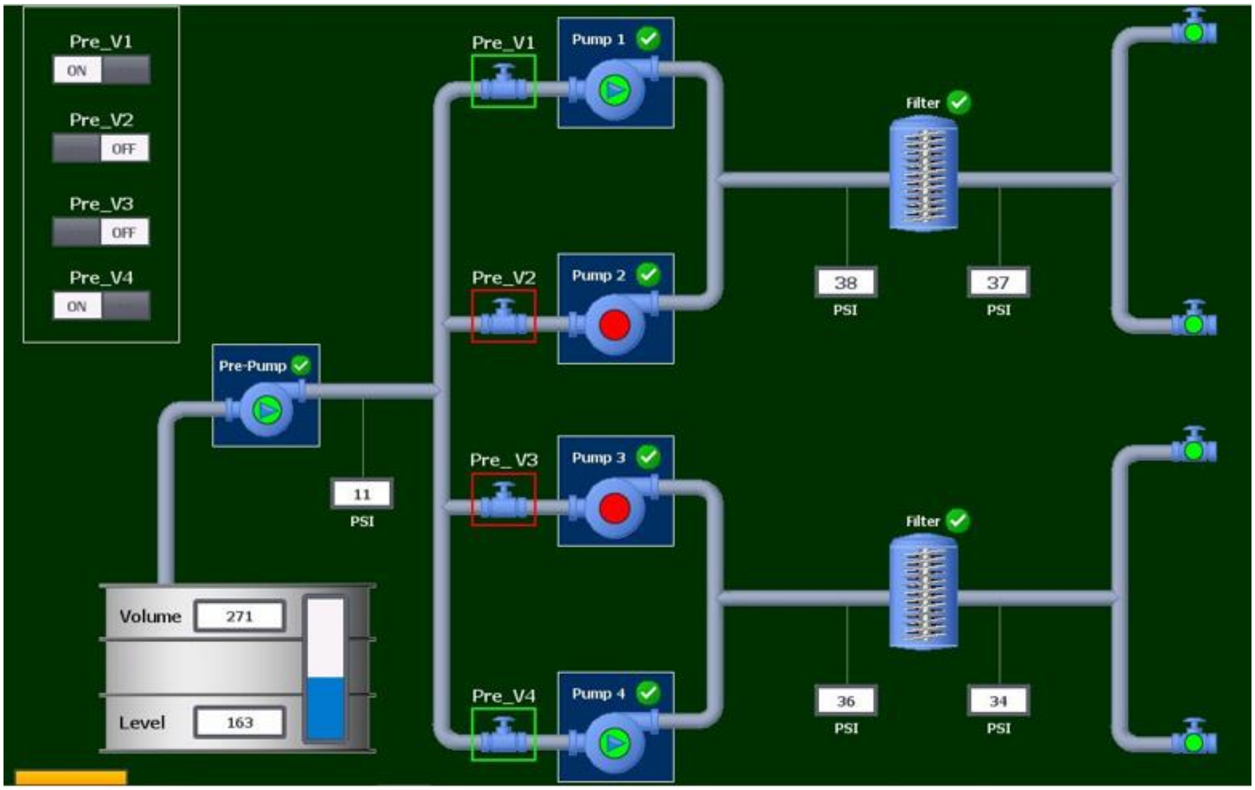

Figure 4.
HMI for system pumps.

2.1.2.3. Plant overview HMI Screen

Due to the large area of the farm, the irrigation control system is divided into two lines, right and left, where each line has two pumps, as shown in figure 5. The area of land is divided into several parts, and each of these parts is irrigated using one valve. Irrigation valves are controlled according to the PLC programme, and the operator assigns settings through the HMI screen. The pumps work at full speed; irrigation is started by one pump in each line; in the event of opening a large number of valves, pressure will be dropped, which will make the control system start the second pump to reach the proper irrigation pressure range. The Plant Overview screen supports the operator with the following data and control facilities:

- Operation status (run/stop) for the irrigation valves.
- Soil moisture and soil conductivity (EC) readings.
- Manual control for the irrigation valves, which will be activated only in system manual mode.

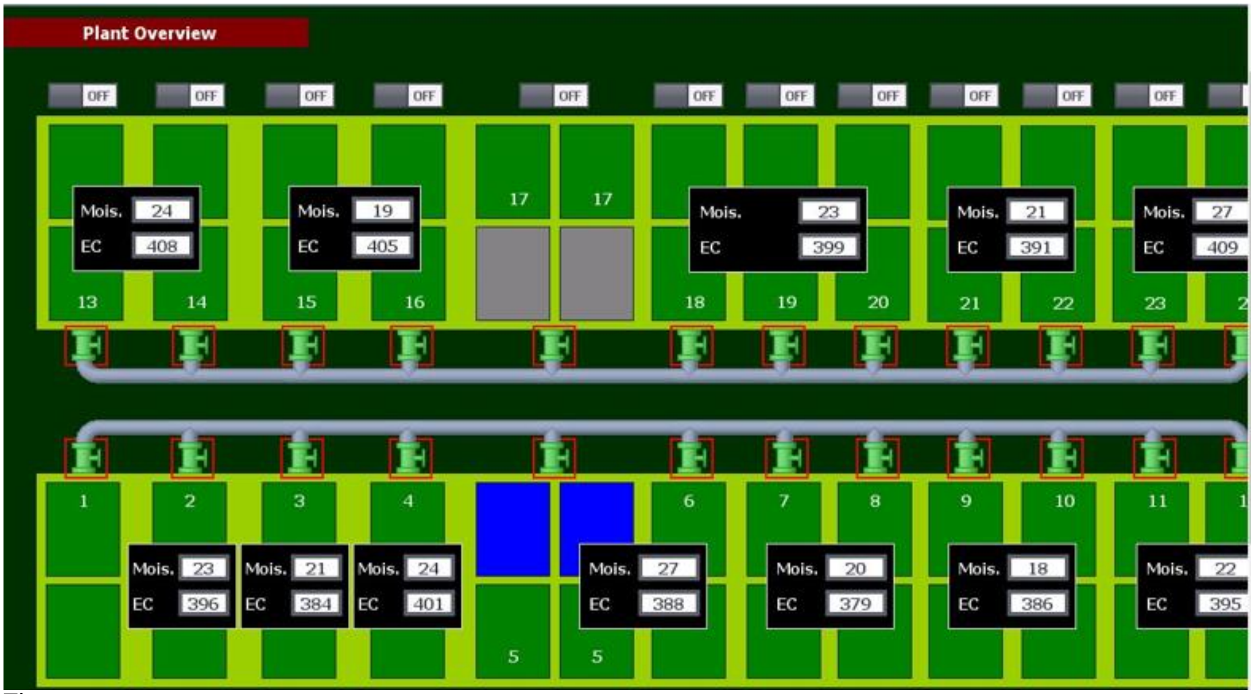

Figure 5.
Plant overview screen.

2.1.2.4. Pumps Conditions HMI Screen

It describes the status of all parameters that are affecting the availability of the system pumps, as shown in figure 6, as follows:

- Screen Enable: Either the pump operation is enabled or not.
- Auto/Man. Switch: showing the status of the operation mode selector switches that are available on the power panel.
- Overload: Status of the overload relay for each pump.
- Start inhibit time: Protect the pumps from frequently restarting orders in a short time.
- Water level: Indicates the availability of irrigation water (the limit is set by the operator).
- Head pressure: Indicates whether the pumps are running within healthy head pressure limits or not (limits are set by the operator).
- Power supply: status of the three-phase power supply for the pumps.
- Weather station: Either the weather is suitable to run the pumps or not.
- Pump ready: Indicates that all the previous conditions for each pump are ready or not.

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Figure 6.
Screen of pumps conditions.

2.1.2.5. System Settings HMI Screen

System parameters can be set by navigating through two screens. system settings 1 and 2, as shown in figures 7 and 8, respectively.

2.1.2.5.1. System Settings 1

Figure 7 shows the system, which contains the following:

- Operation mode.
- Water source.
- Pumps starting time.
- Irrigation time.
- Pumps inhibit time.
- Pumps: Enable or Disable.
- Weather station.
- Filters DP setpoints.
- Pressure setpoints.

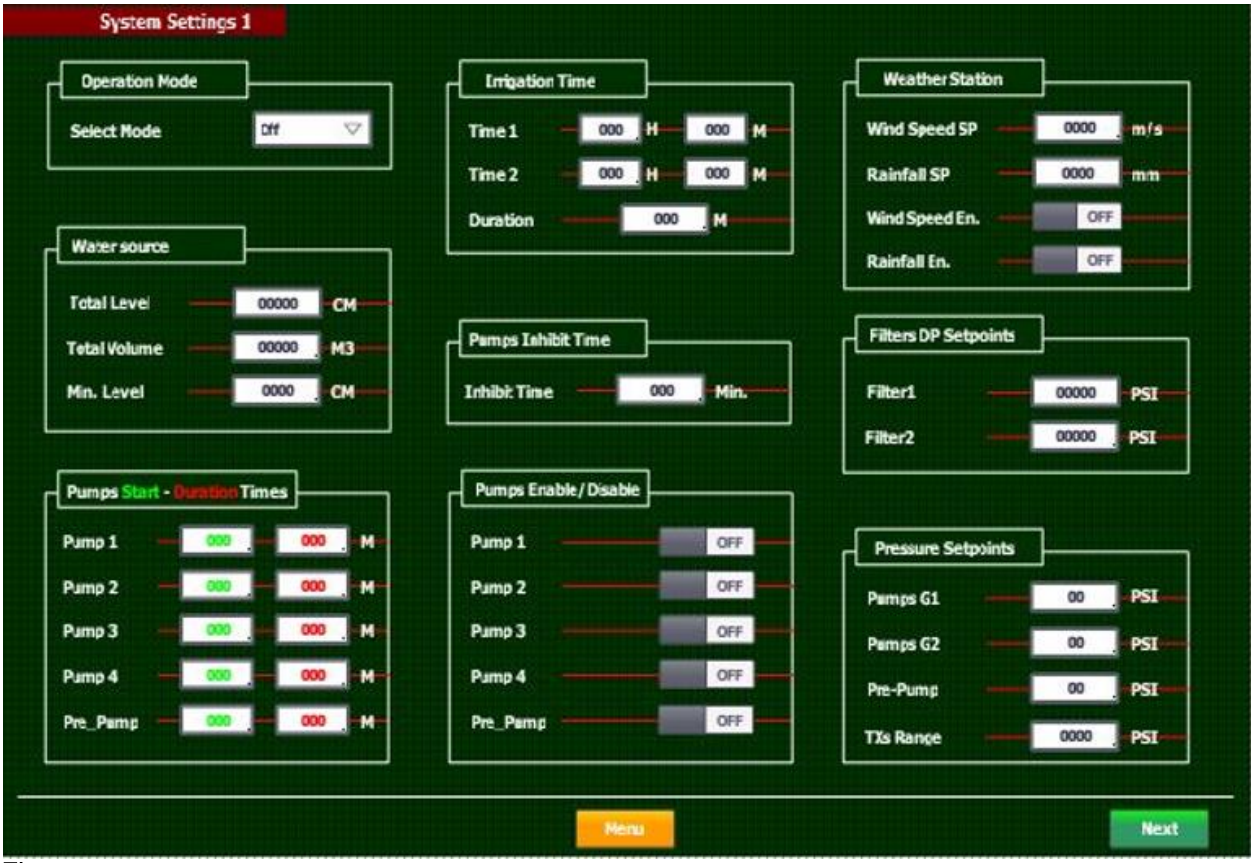

Figure 7.
System settings 1.

2.1.2.5.2. System Settings 2

Figure 8 shows the system adjustment of parameters for all valves.

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Figure 8.
System settings 2.

2.1.2.6. Weather Station HMI Screen

Figure 9 shows the design of a weather station to monitor and display live readings for air temperature, air humidity, atmospheric pressure, wind speed, wind direction, and rainfall.

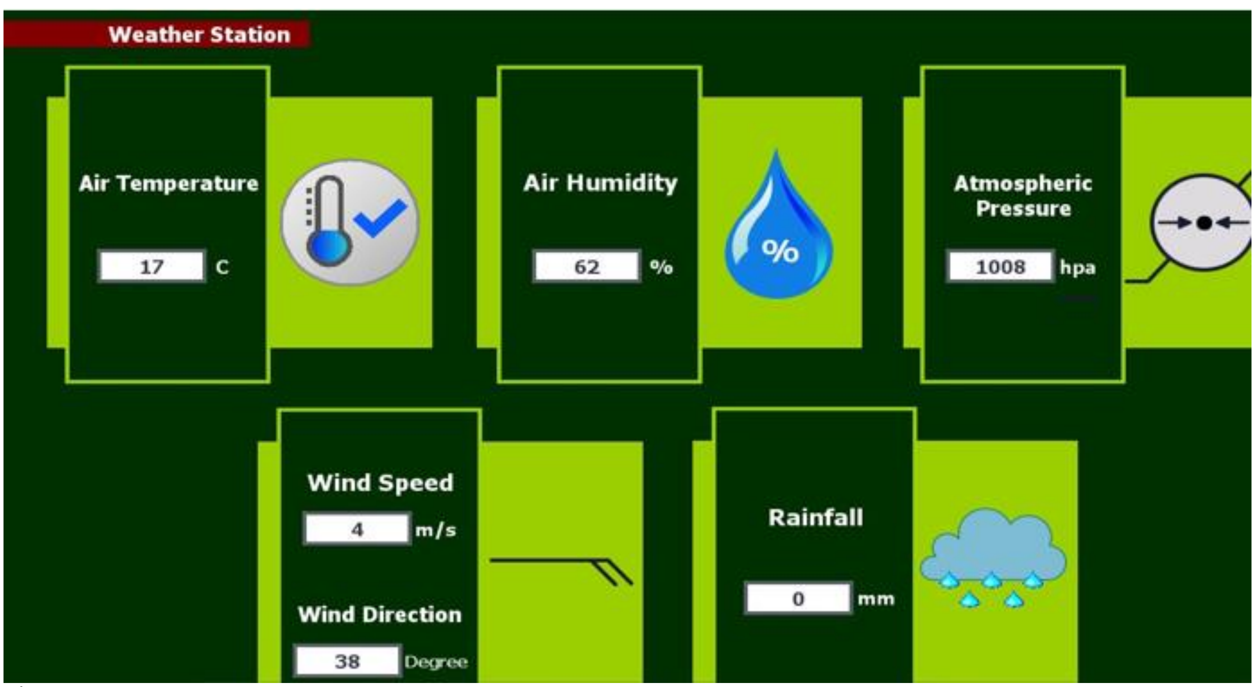

Figure 9.
Weather station control screen.

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2.1.3. System H/W and S/W structure

The implemented design is based on two PLCs: PLC S 7 1214C Siemens as a master and M221 Schneider as a slave. Figure 10 shows the block diagram for the system's hardware H/W and software S/W structures.

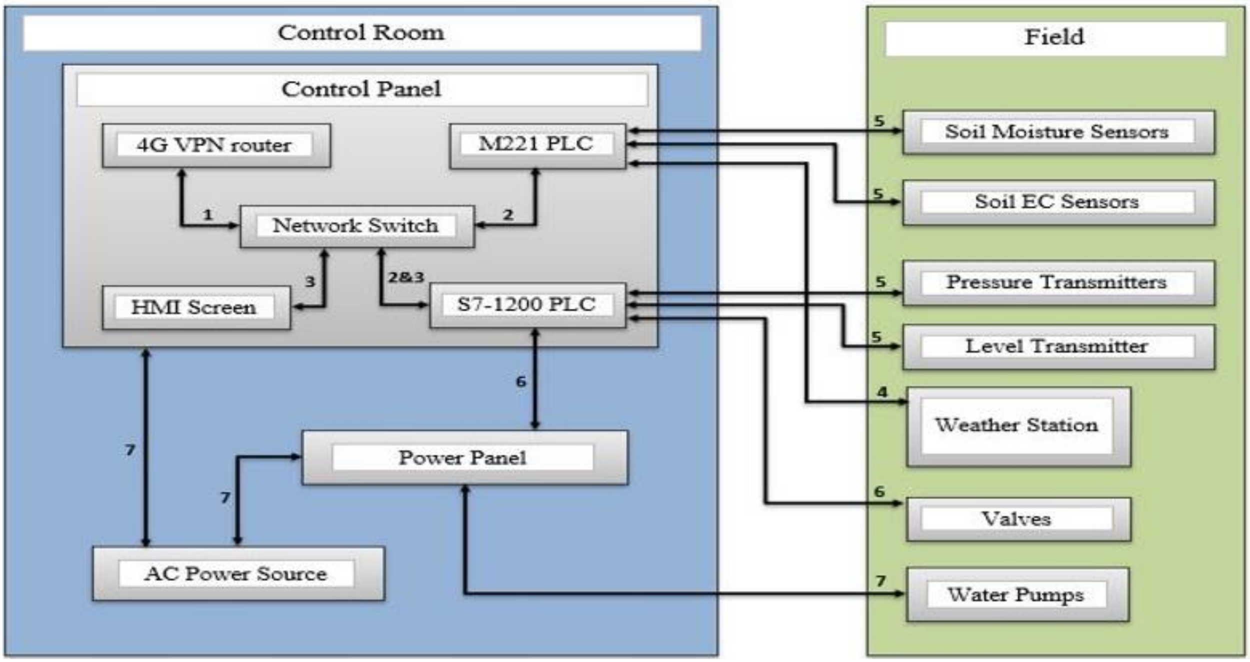

Figure 10.
The block diagram of the system's H/W and S/W structure.

The connection between different parts of the system is implemented as follows:

- Connection between the 4G VPN router and network switch through an Ethernet IP connection.
- Modbus TCP data exchange occurs through an Ethernet connection.
- Profinet data exchange occurs through an Ethernet connection.
- Modbus RTU data exchange between the weather station and Schneider PLC M221 through an RS485 connection.
- Hard-wired analogue signal (0 to 10 Vdc).
- Valve control signal (24 Vac).
- Three-phase power cable.

2.2. Part 2: Fuzzy Logic Control for Irrigation System

Fuzzy logic control based on the Mamdani method and triangular membership functions are used. It depends on a set of linguistic control rules obtained from the measured data from different sensors. IF Then rules are built based on input variables, which are temperature, pressure transmitter, soil moisture, rain fall, humidity, and wind speed, while the water pump state is considered the output variable. Defuzzification is based on the centroid method to get the crisp value of the output.

3. Results and Discussion

This paper is divided into two parts as smart control system for irrigation to determine the number of working pumps needed based on measurements of sensors:

Part 1: PLC and SCADA system control based on HMI screens: Figures 11 and 12 display the actual measurement and the data gathered using field sensors, respectively. Figure 11 displays the actual weather station measurements on an HMI screen, including temperature, humidity, pressure

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transmitter, soil moisture, wind speed, and rain fall. The farm is shown in Figure 12 after the implementation of an automated irrigation control system. It is divided into two irrigation lines to irrigate the farm, two pumps for each line, a total of four pumps for the entire farm, and several control valves placed into the assigned green space to regulate the amount of water applied to a specific crop. Table 2 provides an example of measurements taken over a period of four days for every sensor and the appropriate number of operating pumps. The measurements indicate that in the absence of rain, the soil is dry, the temperature is high, the conductivity is high, the wind speed is low, and the humidity is high. To irrigate the land, the irrigation system requires two pumps for each line. When precipitation, damp soil, low temperature, low conductivity, high wind speed, low humidity, and rain are present, all valves are closed and the operating pumps are turned off.

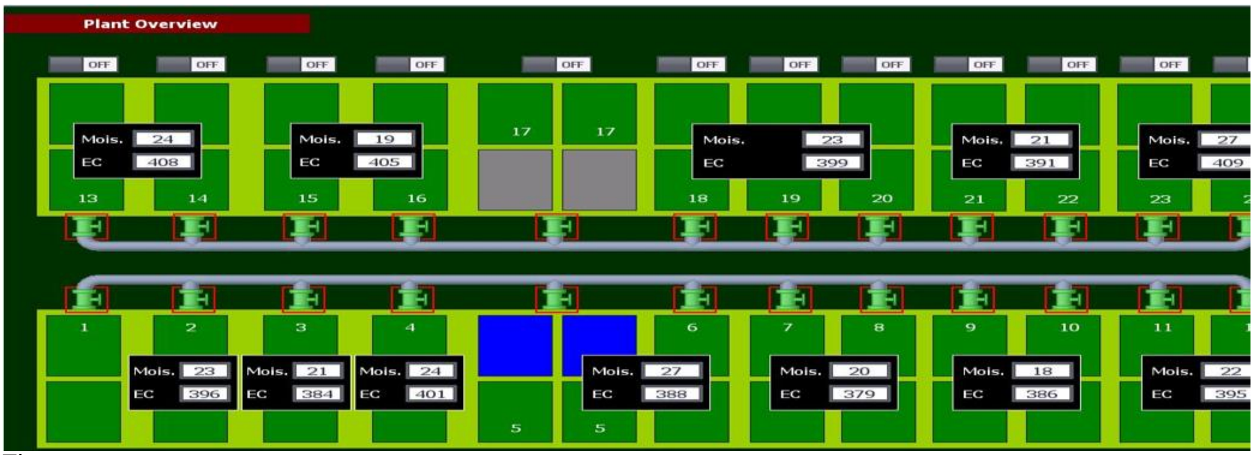

Figure 11.
The farm after implementing automatic irrigation control system.

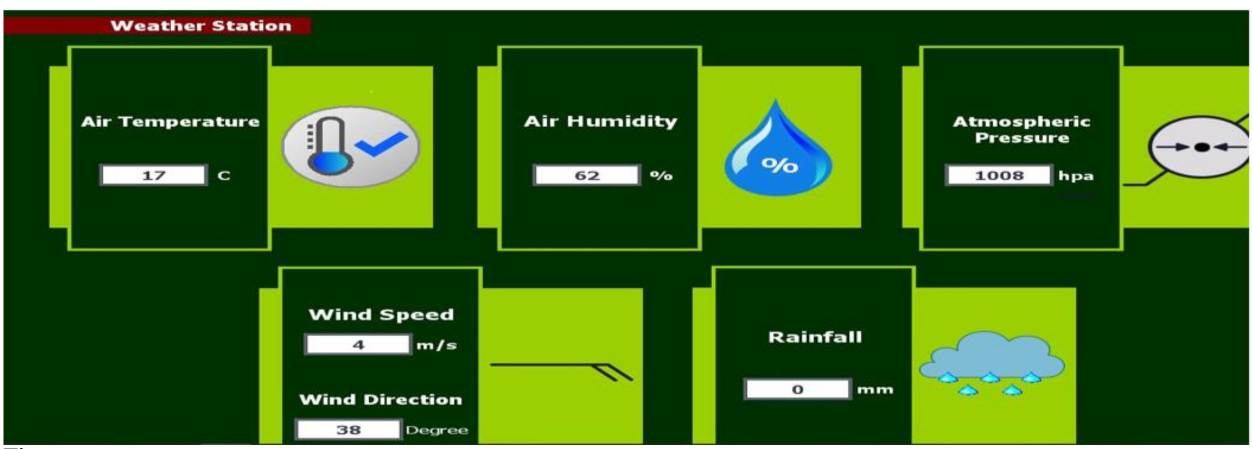

Figure 12.
Weather station actual measurements.

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Table 2.
Sample of measurements.

Days	Soil moisture %	Rain fall mm	Pressure PSI	Wind speed m/s	Conductivity EC(μS/cm)	Temperature C	Humidity %	Number of working pumps per line
1	27	7	36	4	300	18	15	0
2	19	0	25	3	320	30	60	2
3	40	8	28	8	280	15	20	0
4	31	0	22	4	390	28	70	2

In the traditional control system for such irrigation plant, operator runs 2 pumps for each line (total 4 pumps) for 2 hours, 2 times per day (4 hours for each pump per day).

Power of each pump is 22 kw, which means that the total power is 88 kw for 4 hours daily.

By using our smart irrigation control system with the field measuring sensors (Pressure sensors, Soil moisture, Soil EC and Weather station), we found a significant reduction in the power consumption as follows:

- 2 Main Pumps run for 4 hours per day
- 2 Standby pumps run for 1.5 hour per day.

Power consumption and the cost for traditional system versus smart irrigation control system:
The pump in this situation uses 22 kW. To monitor the pump's power usage, conduct this test on a regular basis, either throughout the season or anytime [35]:
Reading an electronic meter:
1^{st} reading = 1264.2 kWh
2^{nd} reading = 1262 kWh
Multiplier stated on power bill = 10 Power usage
Power usage = (1 st reading – 2 nd reading) *multiplier stated on power bill (1)
Power usage= (1264.2-1262) *10 *3600 / 3600 = 22 KW
Power consumed based on the number of operating pumps= Power usage of each pump * No. of operating pumps * working hours (2)
Total daily power consumption per day for the traditional irrigation system =
22KW * 4 pumps * 4 Hours = 352 KWh / Day.
Total daily power consumption per day for the smart irrigation control system =
(22 KW * 2 pumps * 4 Hours) + (22 kw * 2 pumps * 1.5 Hours) = 242 KWh / Day.
The percentage of power reduction per day = (Power consumption per day for the traditional irrigation system - Power consumption per day for the smart irrigation control system) *100 (3)
The percentage of power reduction per day = (352 – 242) / 352) * 100 = 31.25%.
The pumping cost [35]:

Evaluate the cost for pumping. Considering the cost per kWh to compute the power required for pumping. If supplier charges have different rates during the day and night, it could be challenging to calculate the exact charges per kWh.

If supply costs $ 0.5 per kWh: the irrigation system cost = Daily power consumption* Supply cost (4)
The traditional irrigation system cost= 352 kWh x $0.5 = $176
The smart irrigation control system cost= 242KWh*$0.5= $121
The saving in cost per day= $176-$121 =$55
The percentage of cost reduction per day= (($176-$121)/$176) *100=31.25%

Part 2: Fuzzy logic control for irrigation systems: Based on the Mamdani type with triangular membership functions, according to the measurements from different types of sensors, temperature, pressure transmitter, soil moisture, rain fall, humidity, and wind speed are the input variables, while the water pump state is the output variable. Figure 13 shows the fuzzy inference system with all inputs and output variables. The membership functions are divided into four ranges for each input and output variable, which are very low, low, medium, and high. Figure 14 displays the temperature range of 10 to 60 degrees Celsius.

Pressure in the range of 20 to 40 psi is depicted in Figure 15. The range of soil moisture, from 0% to 100%, is displayed in Figure 16. The wind speed range is displayed in Figure 17, from 0 to 8 m/s. The range of rain fall, from 0 to 8 mm, is depicted in Figure 18. The range of humidity, from 0% to 100%, is depicted in Figure 19. The range of operational pumps, from zero to four pumps, is displayed in Figure 20. The measured data is transferred to fifty rules that are fired in parallel using IF THEN rules.

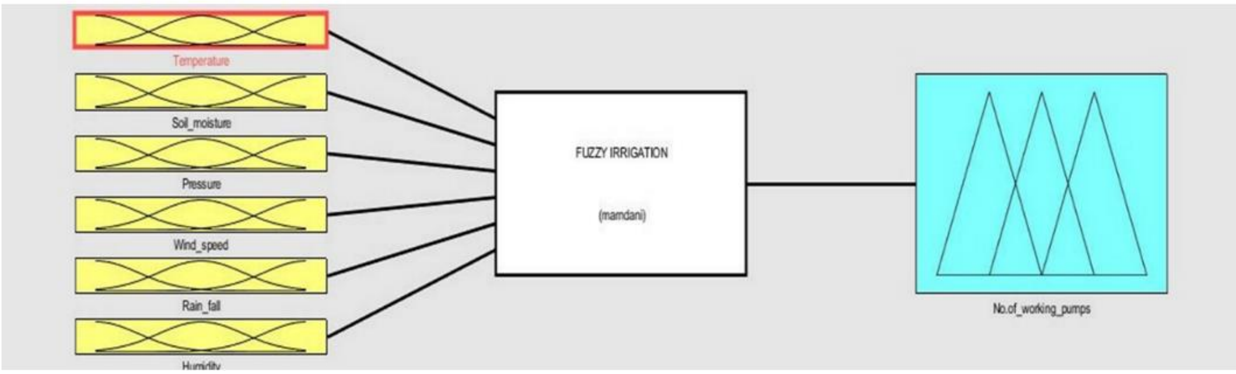

Figure 13.
The fuzzy controller system.

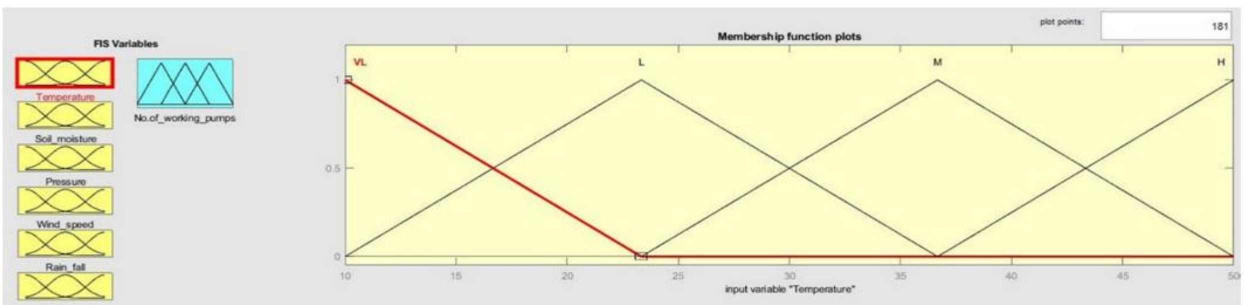

Figure 14.
Temperature membership function.

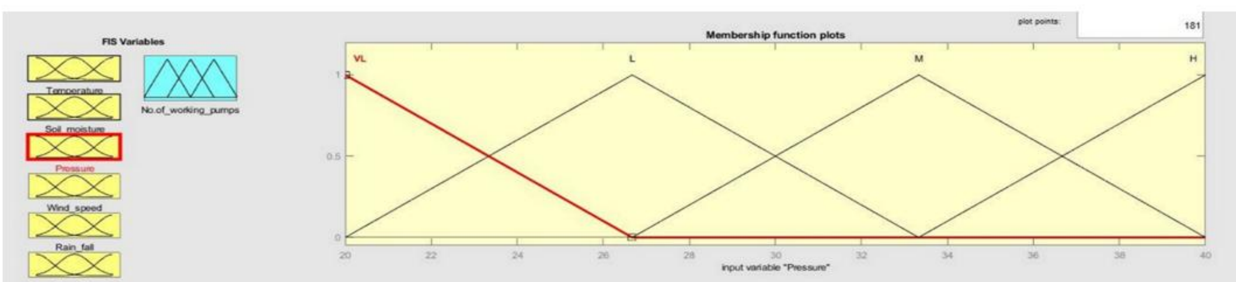

Figure 15.
Pressure membership function.

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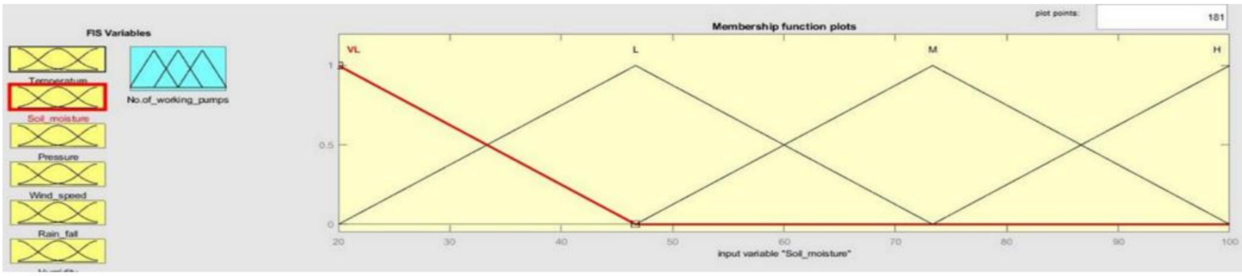

Figure 16.
Soil moisture membership function.

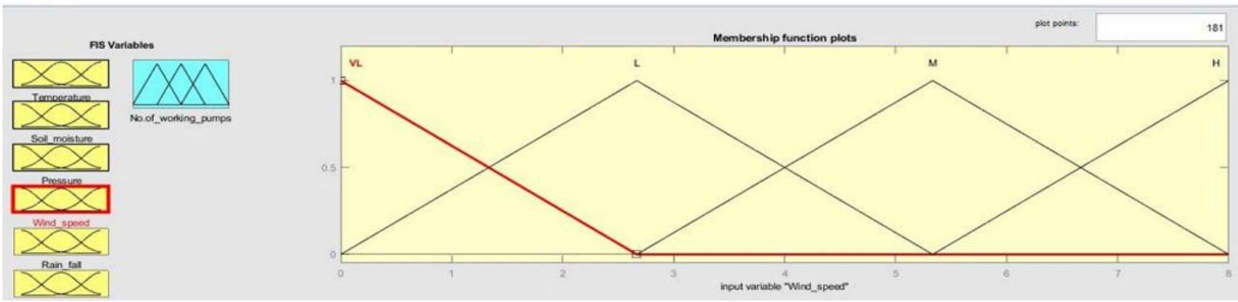

Figure 17.
Wind speed membership function.

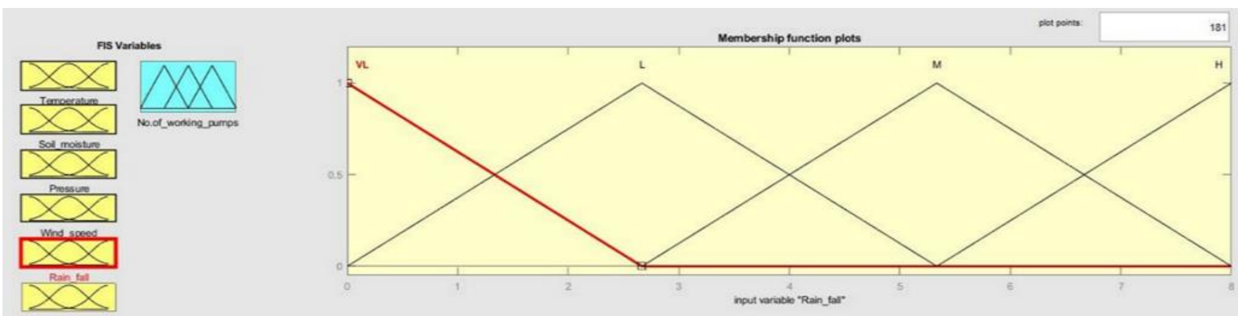

Figure 18.
Rain fall membership function.

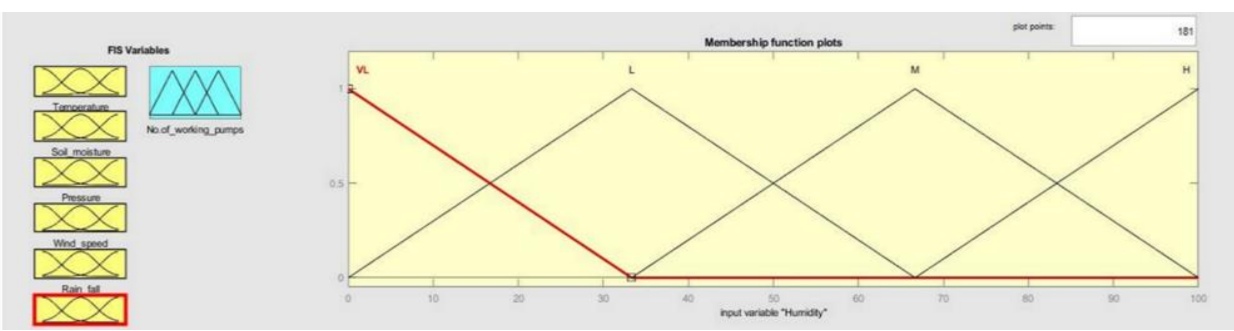

Figure 19.
Humidity membership function.

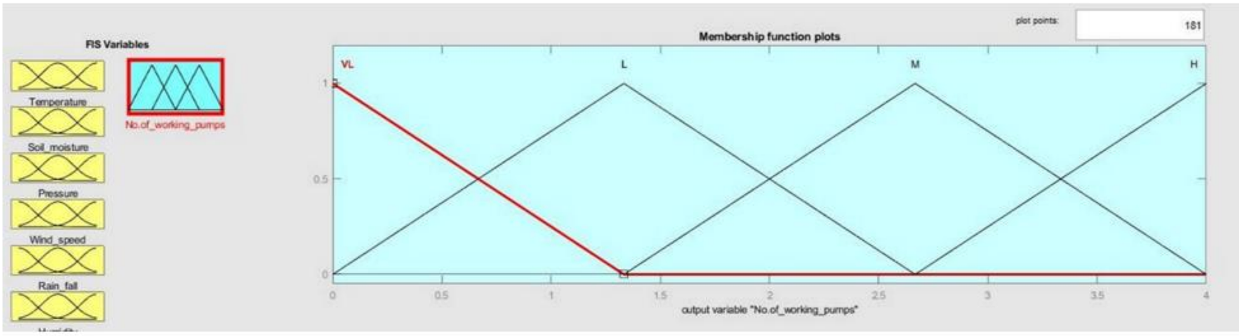

Figure 20.
Number of working pumps membership function.

The implemented design uses the centroid approach for defuzzification and is based on the MATLAB fuzzy logic Mamdani type with a triangle membership function. According to the state of the input parameters, the fuzzy rules viewer for the irrigation control system will predict the appropriate number of operating pumps. The fuzzy rules for managing irrigation pumps are depicted in Figure 21. In this scenario, the conditions of the inputs lead to the output variable of two operating pumps being switched on. In the first scenario, if there is no precipitation, inadequate soil moisture, low wind speed, high temperatures, a high-pressure transmitter, and high humidity, the field needs two working pumps in each line for watering the farm.

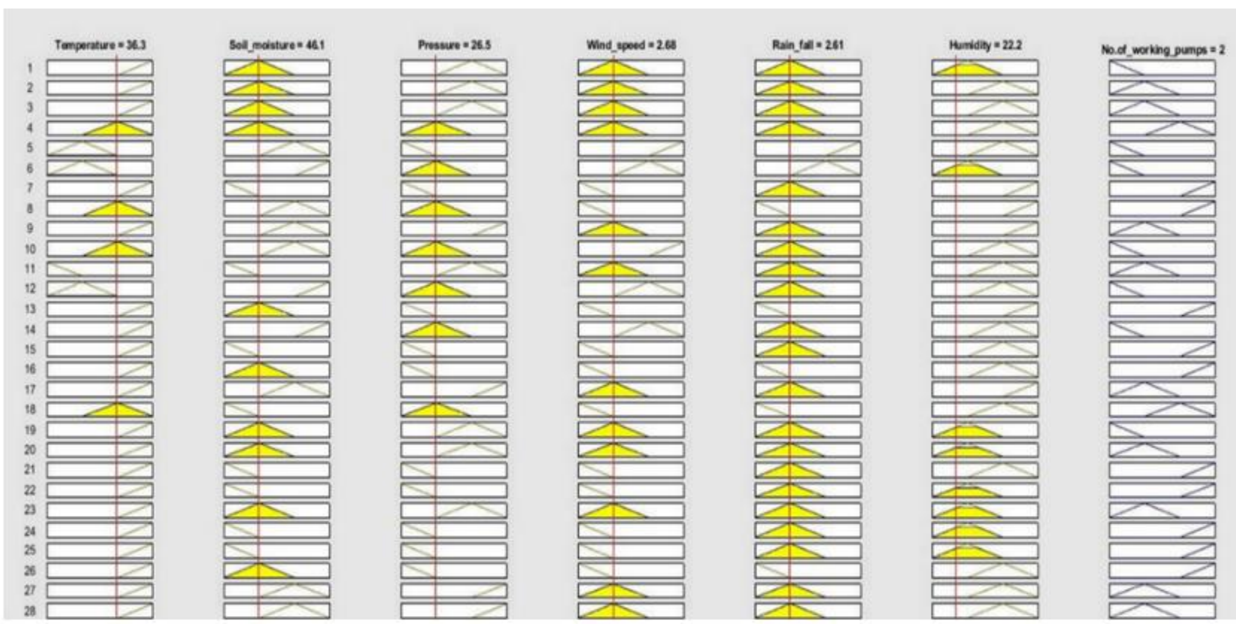

Figure 21.
The fuzzy rules for controlling irrigation (First scenario).

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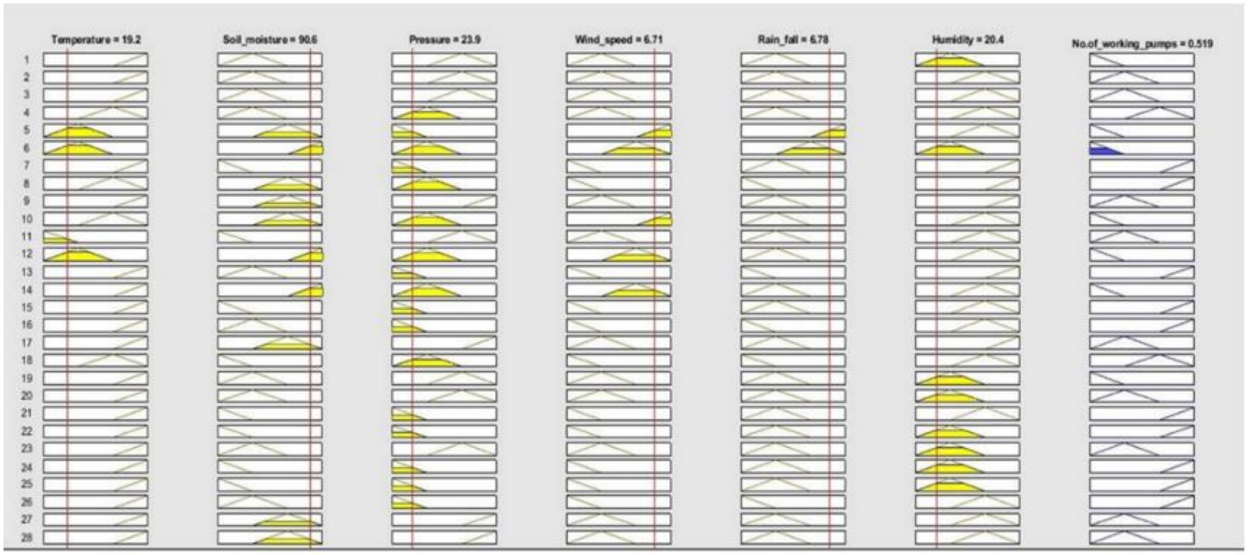

Figure 22.
The fuzzy rules for controlling irrigation pumps (Second scenario).

In the second scenario, as shown in figure 22, when there is a lot of precipitation, high soil moisture content, high wind speed, low temperature, low pressure transmitter value, and low humidity, the operating pumps switch off. Both scenarios demonstrate that the fuzzy control is capable of effectively controlling the number of pumps required for irrigation. The output surface prediction using fuzzy control and the relationships between the input parameters and the number of pumps as output variables are depicted in Figures 23 and 24, respectively. The relationship between soil moisture, rain fall, and the number of operating pumps as input and output variables is shown in Figure 23. It demonstrates the operation of pumps shutting down when there is a lot of moisture in the soil and rain falls. The two working pumps should be employed when the amount of moisture in the soil is at its lowest level and rain is not expected. The relationship between wind speed and pressure transmitter as input variables and the number of operating pumps as the output variable is shown in Figure 24. It illustrates that two working pumps activate when the pressure transmitter and wind speed are both low. The pumps turn off when the wind speed is high and the pressure transmitter is high.

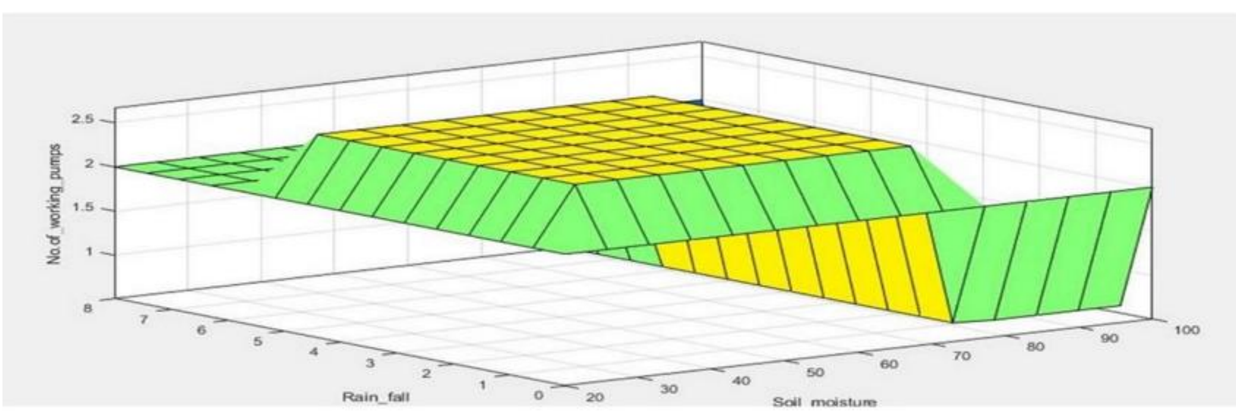

Figure 23.
The relation between soil moisture, rain fall and number of working pumps.

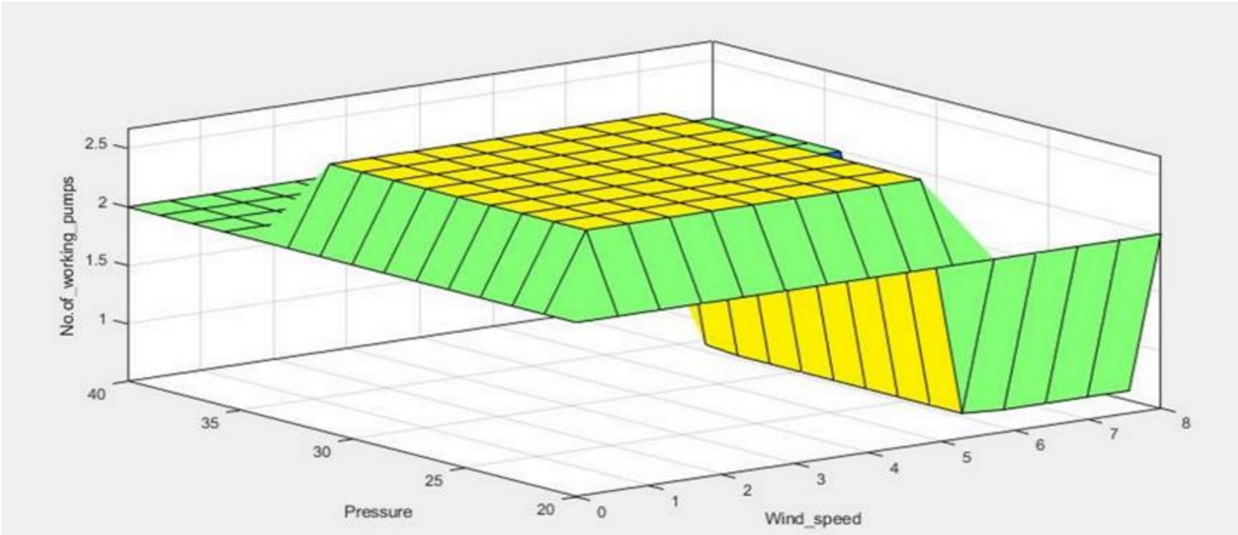

Figure 24.
The relation between wind speed, pressure and number of working pumps.

4. Conclusions

This paper intends to design and implement a smart irrigation control system based on PLC, SCADA system, fuzzy control, and various types of sensors in order to remove human contact and prevent water waste from traditional irrigation systems. In order to monitor and control field sensors and determine the number of effective operating pumps required to irrigate the area, six human machine interface (HMI) screens have been designed. The water pumps are the output variables, and the six input variables—temperature, humidity, soil moisture, pressure transmitter, and wind speed—have been used. With the same input conditions, a fuzzy logic controller predicts an appropriate number of working pumps, resulting in the same output from the PLC and SCADA control systems. The power consumption per day for the traditional irrigation system is 352 KWh/day, while the total daily power consumption per day for the intelligent irrigation control system is 242 KWh/day, achieving reduction rate in power and cost is 31.25%.

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References

[1] M. S. Steffi, P. Visitha, C. Kamal, and S. Steffi, "Automatic Irrigation System Using Programmable Logic Controller," *Int. J. Elec&Electr.Eng&Telecoms*, vol. 1, no. 1, 2015, [Online]. Available: www.ijeetc.com

[2] S. P. Nikam and R. K. Patil, "Automatic Irrigation System Using Scada," 2016. [Online]. Available: https://api.semanticscholar.org/CorpusID:212546972

[3] P. Madhavi, B.Aarthi, B.Nandini, G.Vyshnavi, and P. V. Lakshmi, "AUTOMATED IRRIGATION SYSTEM USING PLC," 2020. [Online]. Available: https://api.semanticscholar.org/CorpusID:247581962

[4] D. Stipanicev and J. Marasovic, "Networked embedded greenhouse monitoring and control," in *Proceedings of 2003 IEEE Conference on Control Applications, 2003. CCA 2003.*, 2003, pp. 1350–1355 vol.2. doi: 10.1109/CCA.2003.1223208.

[5] N. Abdikadir, A. Hassan, H. Osman, and R. A Rashid, "Smart Irrigation System," *Int. J. Electr. Electron. Eng.*, vol. 10, pp. 224–234, Aug. 2023, doi: 10.14445/23488379/IJEEE-V10I8P122.

[6] R. S. Krishnan *et al.*, "Fuzzy Logic based Smart Irrigation System using Internet of Things," *J. Clean. Prod.*, vol. 252, p. 119902, 2020, doi: https://doi.org/10.1016/j.jclepro.2019.119902.

[7] K. Anand, C. Jayakumar, M. Muthu, and S. Amirneni, "Automatic drip irrigation system using fuzzy logic and mobile technology," *2015 IEEE Technol. Innov. ICT Agric. Rural Dev.*, pp. 54–58, 2015, [Online]. Available: https://api.semanticscholar.org/CorpusID:39048645

[8] I. Morsi, A. Zwawi, and M. Deeb, "SCADA/HMI Development for a Multi Stage Desalination Plant," Nov. 2009.

[9] I. Morsi and L. M. El-Din, "SCADA system for oil refinery control," *Measurement*, vol. 47, pp. 5–13, 2014, [Online].

Available: https://api.semanticscholar.org/CorpusID:55673480
[10] A. Darwish, I. Morsi, and A. El Zawawi, "Complete Combustion Control for a Steam Boiler Plant," 2016. [Online]. Available: https://api.semanticscholar.org/CorpusID:138131794
[11] O. Rashad, O. Attallah, and I. Morsi, "A smart PLC-SCADA framework for monitoring petroleum products terminals in industry 4.0 via machine learning," *Meas. Control*, vol. 55, no. 7–8, pp. 830–848, Jul. 2022, doi: 10.1177/00202940221103305.
[12] O. Rashad, O. Attallah, and I. Morsi, *A PLC-SCADA Pipeline for Managing Oil Refineries*. 2022. doi: 10.1109/ICCI54321.2022.9756108.
[13] I. Morsi, M. Mansour, and M. Mostafa, "Wireless Gas Detector System Using Microcontrollers, PLC and SCADA System for Monitoring Environmental Pollution," Jan. 2013.
[14] O. Attallah and I. Morsi, "An electronic nose for identifying multiple combustible/harmful gases and their concentration levels via artificial intelligence," *Measurement*, vol. 199, p. 111458, 2022, doi: https://doi.org/10.1016/j.measurement.2022.111458.
[15] I. Morsi, "Discrimination of some atmospheric gases using an integrated sensor array, surface response modeling algorithms, and analysis of variance (ANOVA)," in *2008 IEEE Sensors Applications Symposium*, 2008, pp. 140–145. doi: 10.1109/SAS13374.2008.4472959.
[16] I. Morsi, "Electronic noses for monitoring environmental pollution and building regression model," in *2008 34th Annual Conference of IEEE Industrial Electronics*, 2008, pp. 1730–1735. doi: 10.1109/IECON.2008.4758215.
[17] I. Morsi, "Electronic Nose System and Artificial Intelligent Techniques for Gases Identification," F. Balasa, Ed., Rijeka: IntechOpen, 2010, p. Ch. 11. doi: 10.5772/8873.
[18] L. A. Zadeh, "Outline of a New Approach to the Analysis of Complex Systems and Decision Processes," *IEEE Trans. Syst. Man. Cybern.*, vol. SMC-3, no. 1, pp. 28–44, 1973, doi: 10.1109/TSMC.1973.5408575.
[19] M. M. H. Khan *et al.*, *Green Buildings and Indoor Air Quality: A Health and Technological Review*. 2023. doi: 10.20944/preprints202308.0368.v1.
[20] V. Khatri, "Application of Fuzzy logic in water irrigation system," *Int. Res. J. Eng. Technol. (IRJET*, vol. 5, no. 4, pp. 3372–3375, 2018, [Online]. Available: www.irjet.net
[21] T. Wanyama and B. H. Far, "Multi-Agent System for Irrigation Using Fuzzy Logic Algorithm and Open Platform Communication Data Access," *World Acad. Sci. Eng. Technol. Int. J. Comput. Inf. Eng.*, vol. 11, pp. 690–695, 2017, [Online]. Available: https://api.semanticscholar.org/CorpusID:63192729
[22] M. Vadiati, D. Nalley, J. F. Adamowski, M. Nakhaei, and A. Asghari-Moghaddam, "A comparative study of fuzzy logic-based models for groundwater quality evaluation based on irrigation indices," *J. Water L. Dev.*, vol. 43, pp. 158–170, 2019, [Online]. Available: https://api.semanticscholar.org/CorpusID:210074693
[23] A. K. Singh, T. Tariq, M. F. Ahmer, G. Sharma, P. N. Bokoro, and T. Shongwe, "Intelligent Control of Irrigation Systems Using Fuzzy Logic Controller," *Energies*, vol. 15, no. 19. 2022. doi: 10.3390/en15197199.
[24] S. Rajaprakash, R. Jaichandran, P. R P, and A. Nagappan, "Fuzzy logic controller for effective irrigation based on field soil moisture and availability of water," *J. Adv. Res. Dyn. Control Syst.*, vol. 9, pp. 90–97, Jan. 2017.
[25] D. Viais, C. Cremasco, D. Bordin, F. Putti, J. Silva Junior, and L. R. A. Gabriel Filho, "FUZZY MODELING OF THE EFFECTS OF IRRIGATION AND WATER SALINITY IN HARVEST POINT OF TOMATO CROP. PART I: DESCRIPTION OF THE METHOD," *Eng. Agrícola*, vol. 39, pp. 294–304, Jun. 2019, doi: 10.1590/1809-4430-eng.agric.v39n3p294-304/2019.
[26] D. Widyawati and A. Ambarwari, "Fuzzy Logic Design to Control the Duration of Irrigation Time in the Greenhouse," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1012, p. 12086, Apr. 2022, doi: 10.1088/1755-1315/1012/1/012086.
[27] I. Morsi, Y. Elsherief, and A. El Zawawi, "A Security System and Employees Performance Evaluation Using RFID Sensors and Fuzzy Logic," *2009 Comput. World Futur. Comput. Serv. Comput. Cogn. Adapt. Content, Patterns*, pp. 597–602, 2009, [Online]. Available: https://api.semanticscholar.org/CorpusID:23882405
[28] M. Amgad, I. Morsi, and M. M. M. Omar, "Control Ports Authorities' Equipment Based on RFID and SQL Security System," *J. Phys. Conf. Ser.*, vol. 2128, no. 1, 2021, doi: 10.1088/1742-6596/2128/1/012002.
[29] S. industry Mall, "Siemens industry mall." Accessed: Jan. 05, 2024. [Online]. Available: https://mall.industry.siemens.com/mall/en/ww/Catalog/Product/?mlfb=6ES7214-1AG40-0XB0. [Accessed: 10-JUNE-2023].
[30] S. Electric, "Schneider Electric." [Accessed: 10-JUNE-2023].
[31] "Siemens." Accessed: Jan. 05, 2024. [Online]. Available: https://support.industry.siemens.com/cs/pd/199323?pdti=pi&dl=en&lc=en-DE [Accessed: 10-JUNE-2023].
[32] Telemecanique Sensors, "Telemecanique Sensors." Accessed: Jan. 05, 2024. [Online]. Available: https://telemecaniquesensors.com/dk/en/product/reference/XMLG010D71[Accessed: 10-JUNE-2023]..
[33] WIKA, "WIKA." Accessed: Jan. 05, 2024. [Online]. Available: https://www.wika.com/en-en/ls_10.WIKA. [Accessed: 10-JUNE-2023].
[34] HD, "HD." Accessed: Jan. 05, 2024. [Online]. Available: https://www.hondetechco.com/soil-moisture-temperature-ec-salinity-4-in-1-sensor-product/ . [Accessed: 10-JUNE-2023].
[35] E. P. Meter, "Electric Irrigation Pumps - Performance and Efficiency," no. January, pp. 1–12, 2015.