Fuzzy Logic Implementation for Power Efficiency and Reliable Irrigation System (PERIS) of Tomatoes Smart Farm

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Abstract—This paper presents an intelligent motor speed controller for Three Phase Motor with Variable Frequency Driver (VFD) for irrigation system of Smart Farming using fuzzy logic algorithm developed inside a Micro-Control Unit (MCU) environment or MCU on Power Efficiency and Reliable Irrigation System (PERIS). The desired motor speed controller is obtained using fuzzy inputs that consider three phenomenon such as: availability of energy within the system, reservoir water level and environment temperature. These fuzzy inputs are feedback data from the water reservoir level sensor (plant water requirements), environment/temperature sensor and current sensor. Different frequencies were used to test the controller’s performance in real time undergoing different water level and power load variations. The whole system is powered by photovoltaic cells, it can quickly and accurately calculate water demand amounts of crops, which can provide a scientific basis for power-savings and water-savings for irrigation. Experiment results showed that the developed controller is efficient, reliable and robust.

Index Terms—Fuzzy Logic; Irrigation System; Micro-Control Unit; Motor Speed Control; Smart Farm; Three Phase Motor.

I. INTRODUCTION

Food security is a major problem the world faces today [1]. The effect of global warming coupled with the world population explosion poses a big challenge to solve this problem. The unpredictable weather conditions evidently destroyed agricultural products [2]. In addition, due to climate change, the power/energy generation is compromised that resulted in crops water irrigation problem [3]. As a result, decreasing of agricultural products such as rice, corn, tomato, etc. was sentiment by the farmers especially during offseason. tomato was considered as one of the most cultivated vegetables around the globe and it is extensively grown as secondary crop from rice and corn based farming system [4]. Consumption of tomato continues to increase around the globe [5].

To address the increasing demand of tomato, year round tomato production is the answer, thus, environment real time monitoring and water management are the important things to consider in smart farming. In this research, the focus of smart farming is to use new technology using fuzzy logic control to be program at MCU to drive VFD for motor control system that can give continuous site-specific plant production with consideration of environmental temperature, power availability and reservoir water level.

Plant grow are directly affecting by both factor of environment and water management [6]. Different real time monitoring for irrigation system were introduce by various researcher [7,8,9] but without consideration of power availability and environment temperature. Motor control management are necessary for power efficiency of the system [10]. Variable motor speed result into non-linear condition, thus, this involves the use of mathematical modeling to solve and understand complex nonlinear problems during motor operation [11], [12]. The uniqueness of this system is that, by using fuzzy logic developed in MCU, new circuit design of Input / Output (I/O) module & 12Vdc power supply that can provided an intelligent learning for power management and irrigation system as seen in Figure 1. By using photo voltaic cell as a source of energy, these can be install and use at any remote and isolated farm even without availability of commercial power.

II. POWER AND WATER SOURCE GENERATION FOR THE TOMATOES SMART FARMING

A. Water Source Generation

Deep irrigation must prefer for tomato and it seems semi-regular rather than light, daily irrigation [13]. One to two inches or one gallon of water each week are the basic requirements of each tomato plants, but more accurately one gallon of water for five days [14]. Infrequent or irregular
irrigations for tomato plant resulting to stress and growth development problems, including blossom end rot and cracked or split fruit [15]. It is required to maintain a minimum of 25 psi on water supply to have a good performance for automatic sprinkler irrigation and drip irrigation [16]. To address this needs, constant water supply must retain. These can be done using automated Jack Pump Well, driven by one horse power (1HP) three phase motor as shown from Figure 1 and Figure 2.

Three phase motor was triggered and drove by VFD to provide different frequencies for one horse power-three phase motor to allow nonlinear speed requirements for the motor, these can be seen on Figure 1. Varying the speed of inductive motor will result to savings of energy consumption in the system [17]. The VFD was depend on the signal coming from MCU, where the fuzzy logic program developed. It has a three nonlinear input variables such as; (a) different levels of water reservoir/tank, (b) Environment Temperature, and (c) Availability of Energy in the System.

Since the three phase motor are operated in 220VAC, it will give an effect of electrical spike on other parts of the circuit in the system that will result to intermittent function of signals. Thus, to eliminate these effect of electrical spike, the researchers designed a novel I/O module that specific for these application to connect MCU and VFD without any interfering of electrical spikes on the other parts of the circuits, this can be seen at Figure 3.

The circuit I/O module on Figure 3 uses Opto-Isolation that allows transmission of information between two circuits, without making an electrical connection between them. Instead, the information transmitted as light. These serves as peripheral bridge between the MCU having a fuzzy logic program and VFD that drove the three phase-one horse power (1HP) inductive motor. It uses photo-transistors to separate electrically both side of the circuit from MCU to VFD, but connected by means of light signal from the photo-transistor.

Designing for this circuit at any application can be possible by choosing appropriate resistor values. Using KCL at the microcontroller pin can do so. The pin itself draws zero current, because it is an input, and the capacitor draws zero current at DC. Turning conductance instead of resistance can be apply to make it easier approach using mathematical computation, $G_1 = 1/R_1$, $G_2 = 1/R_2$, and $G_3 = 1/R_3$. The KCL gives:

$$\begin{align*}
(V_{\text{adc}}-5)/R_3+(V_{\text{adc}}-V_{\text{measured}})/R_1+V_{\text{adc}}/R_2=0 \\
G_3(V_{\text{adc}}-5)+G_1(V_{\text{adc}}-V_{\text{measured}})+G_2V_{\text{adc}}=0 \\
(G_1+G_2+G_3)V_{\text{adc}}=G_3V_{\text{measured}}+G_1V_{\text{measured}}
\end{align*}$$

(1)

B. Irrigation System
This study use both sprinkler and drip irrigation system that can be seen at Figure 4. The water reservoir/tank used can store 1500 liters of water. For this study, maintaining 25 psi of water supply was required to give good operation performance for automated drip irrigation and sprinkler irrigation system. Thus, to maintain 25 psi, equation 2 used for computation and it will give the result of having a minimum content of 1000 liters of water in water reservoir.

In getting the water psi of this study, considering formula shown below. One pound per square inch (psi) of pressure can be created using a 1-in. square column of water nearly 28 inches or 2.31 feet high. This is calculated from the two relationships developed [18].

$$\begin{align*}
1 \text{ psi} &= \frac{0.036 \text{ psi}}{x \text{ inches}} \\
\frac{1}{x} &= 0.036 \\
x &= 27.7 \text{ inches} \\
0.433 \text{ psi} &= \frac{1 \text{ psi}}{x \text{ feet}} \\
0.433x &= 1 \\
x &= 2.31 \text{ feet}
\end{align*}$$

Because pressure changes with differences in elevation, two useful relationships to consider are:
Temperature requirements for tomato are between 14 degree to 24 degree Celsius [19]. Sprinkler irrigation system was not only for watering the plant but also to help lowering the temperature and humidity from 4.5 percent to 7 percent of temperature for a certain area [20], while drip irrigation used to increase the soil moisture content of plant plot. Figure 4 shows actual irrigation system implemented using both drip irrigation and sprinkler irrigation. Using soil moisture sensor allows to trigger the solenoid valve to on/off state for drip irrigation system, while the temperature sensor allows to trigger the solenoid valve for sprinkler irrigation system. In these study, the researchers also experiment and observe to determine the specific effect of rainfall warning to Induction motor into 6 hours within a day, succeeding day need 2 hours to maintain a minimum of 25 psi water pressure as discussed from 2.1.1, these will result to an induction motor of 1HP (746Watts) three phase induction motor, MCU and VFD as shown in Figure 1. Thus, optimization of power in the system was required to maximize the operation. In this paper, a three phase one horsepower (1HP or 746Watts) induction motor was used to pump and generate water from a deep well. Using three phase induction motor, it will give more power efficiency consumption compared to single phase induction motor [21].

Three phase induction motor switch into ON/OFF having different frequency controlled by means of MCU with a program of fuzzy logic. Table 2 shows the average value of Output Power (Po), Power Loss (Pl) due to core, switch, heat, etc., and Input Power (Pi) from Table 2 of single phase and three phase motor. Comparison of power efficiency for single phase and three phase motor are computed using formula given from the table.

To fill up the water tank/reservoir, it is require to run the induction motor into 6 hours within a day, succeeding day need 2 hours to maintain a minimum of 25 psi water pressure as discussed from 2.1.1, these will result to an average of 1 hour and 8 minutes operation of motor per day.

Table 1 serves as a reference for the soil moisture sensor to trigger the solenoid valve for drip irrigation. It was found out using equation 3 that drip irrigation operates and triggered at the range of 0-7.5mm of precipitation of water.

\[
\text{Consumption(mm)} = \text{1 tomato} \times \left( \frac{1 \text{ gallon}}{5 \text{ days/tomato}} \right) \times \left( \frac{4 \text{ liters}}{1 \text{ gallon}} \right) \times \left( \frac{1 \text{ mm}}{1 \text{ inch}} \right)
\]

### C. Electric Power Source Optimization

These research use and promote renewable energy, in Figure 2 shows that the main source of power came from solar energy. It consists of 10 pcs (100 watts each) solar panel having a total of 1kWatts, with 4 pcs. of storage battery (12 Volts/100Ah) connected in parallel to the 12Vdc to 220Vac inverter. It support power operation for 1HP (746Watts) three phase induction motor, MCU and VFD as shown in Figure 1. Thus, optimization of power in the system was required to maximize the operation. In this paper, a three phase one horsepower (1HP or 746Watts) induction motor was used to pump and generate water from a deep well. Using three phase induction motor, it will give more power efficiency consumption compared to single phase induction motor [21].

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### Table 1

<table>
<thead>
<tr>
<th>Rain Warning</th>
<th>Precipitation (mm)</th>
<th>Soil Res. (Ω)</th>
<th>Byte (kB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>white</td>
<td>0 - 2.5</td>
<td>3M</td>
<td>770</td>
</tr>
<tr>
<td></td>
<td>2.5 - 5</td>
<td>1.57M</td>
<td>660</td>
</tr>
<tr>
<td></td>
<td>5 - 7.5</td>
<td>340k</td>
<td>505</td>
</tr>
<tr>
<td></td>
<td>7.5 - 10</td>
<td>310k</td>
<td>500</td>
</tr>
<tr>
<td>yellow</td>
<td>10 - 12.5</td>
<td>160k</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>12.5 - 15</td>
<td>145k</td>
<td>437</td>
</tr>
<tr>
<td></td>
<td>15 - 17.5</td>
<td>135k</td>
<td>426</td>
</tr>
<tr>
<td></td>
<td>17.5 - 20</td>
<td>120k</td>
<td>425</td>
</tr>
<tr>
<td>orange</td>
<td>20 - 22.5</td>
<td>105k</td>
<td>424</td>
</tr>
<tr>
<td></td>
<td>22.5 - 25</td>
<td>80k</td>
<td>414</td>
</tr>
<tr>
<td></td>
<td>25 - 27.5</td>
<td>30k</td>
<td>402</td>
</tr>
<tr>
<td></td>
<td>27.5 - 30</td>
<td>5k</td>
<td>399</td>
</tr>
<tr>
<td>red</td>
<td>30+</td>
<td>700</td>
<td>397</td>
</tr>
</tbody>
</table>
Figure 5 shows the designed 12Vdc power supply dedicated for MCU and I/O special purposes to eliminate the effect of electric spike on the circuits due to the use of induction motor. To ensure the filter of signal, it uses 1000μF capacitor after the rectifier connected in parallel and another 100μF & 0.1μF capacitor after IC-7812 regulator also connected in parallel.

III. PROCESS INVOLVED IN FORMULATING THE FUZZY-MCU FOR POWER OPTIMIZATION & WATER SOURCE GENERATION

A. Fuzzy-MCU Process Flow

Figure 6 shows the process flow of fuzzy control implementation to power optimization and water source generation using MCU. The main condition references of motor speed are the value of Available Energy (AE), as seen from Table 3. Available Energy are categorized as; Stop (S) ≤ 50, Extremely Low (EL) from 60%, Low (L) from 70%, Medium (M) from 80%, and High (H) from 90% > . Another input, process value (water level and Temperature) that obtained as the feedback value of variable frequency drive (VFD). VFD is a device used to control AC motor speed and torque by varying its input frequency and voltage [22].

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Fuzzy Rules for Available Energy, Temperature and Water Level.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ES=Extremely Slow, S=Slow, M=Moderate, H=High</td>
</tr>
<tr>
<td>Condition</td>
<td>Temperature (T)</td>
</tr>
<tr>
<td></td>
<td>60 (EL)</td>
</tr>
<tr>
<td>Low</td>
<td>Low EN</td>
</tr>
<tr>
<td>Low Med.</td>
<td>Low EN</td>
</tr>
<tr>
<td>Low Med.</td>
<td>Low EN</td>
</tr>
<tr>
<td>Med.</td>
<td>Med. EN</td>
</tr>
<tr>
<td>Med.</td>
<td>Med. EN</td>
</tr>
<tr>
<td>High</td>
<td>Low S</td>
</tr>
<tr>
<td>High Med.</td>
<td>Med. S</td>
</tr>
<tr>
<td>High Med.</td>
<td>Med. S</td>
</tr>
<tr>
<td>High Med.</td>
<td>Med. S</td>
</tr>
</tbody>
</table>

B. Fuzzy Inputs

The researchers use the fuzzy MUltipleXer (fMUX) as shown on Figure 8 to minimize the fuzzy rules, from 27 fuzzy rules into 9 fuzzy rules, input variables into Temperature (T) and Water Level (WL). A fuzzy multiplexer or (fMUX) acts as a fuzzy switch to select one of the fuzzy inputs. Selection of the inputs is determined by the value of candidate inputs termed as “Select Inputs” [25]. Available Energy are categorized as; Stop (S) from 0 to 50%, Extremely Low (EL) from 60%, Low (L) from 70%, Medium (M) from 80%, and High (H) >90% as shown from Table 3. The three phase induction motor for water pump are in OFF state at 50% and below (≤ 50%) of the Available Energy. Using the Table 3 for fuzzy rules, the induction motor will turn ON at approaching 60 percent and above (≥ 60%) base providing different motor speed base on condition of Temperature and Water Level as shown.

C. Design of fMUX

Figure 9 shows block diagram of fuzzy multiplexer (or fMUX). The function of fMUX can select one of several analog or digital input signals and forwards the selected input into a single line using selection logic provided by select lines. The basic fuzzy multiplexer, fMUX, realizes fuzzy multiplexing by the general expression [26].
\[
Z = (EL \cdot S_0 \cdot S_1) + (L \cdot S_0 \cdot S_1) + (M \cdot S_0 \cdot S_1) + (H \cdot S_0 \cdot S_1)
\]  

(4)

where the logic operations (\* and +) are implemented using some \( S_0 \) and \( S_1 \).

![Figure 9: Fuzzifier using five (5) membership functions (S, EL, L, M and H).](image)

IV. EXPERIMENT RESULTS

Table 2 and Table 3 shows the summary of input voltage \( V_i \), input current \( I_i \) and computed input power \( P_i \) having a formula from equation 5, with additional constant of 1.4 for inverter loss. Output voltage \( V_o \) and output current \( I_o \) and computed RMS output power of \( P_o \) having formula of Equation 6 and computed value of system efficiency using the formula of Equation 7.

\[
P_i = V_i \times I_i + 1.4
\]

(5)

\[
P_o = V_o \times I_o \times \sqrt{3}
\]

(6)

\[
\eta \% = \left( \frac{P_o - P_L}{P_i} \right) \times 100
\]

(7)

Using three phase induction motor with VFD and MCU, C language for coding the program and adopting the fuzzy control flow chart diagram from Figure 6, implementing the fuzzy rules from Table 3. The responds of motor can be seen at figure 11, it indicates that the energy usage or consumptions for the whole system for irrigations are very minimal. Using the formula from equation 6 for getting the energy consumption calculation, energy \( E \) in kilowatt-hours (kWh) per day is equal to the power \( P \) in watts (W) times number of usage hours per day \( t \) divided by 1000 watts per kilowatt.

\[
E_{(kWh/day)} = \frac{P(W) \times t_{(h/day)}}{1000(kW/W)}
\]

(8)

Using formula from Equation 8, having parameters of; inverter to convert DC to AC efficiency is 90%; power factor of the Operating Induction Motor is 0.85 (The power factor of induction motors varies with load, typically from around 0.85 or 0.90 at full load to as low as 0.35 at no-load, due to stator and rotor leakage and magnetizing reactance); Line to line Voltage 400V and Frequency be 60Hz, star winded Stator; motor full load efficiency is 85% (Full load motor efficiency varies from about 85 % to 97 %, related motor losses being broken down roughly as follows: Friction and windage5%–15%, Iron or core losses, 15%–25%, Stator losses, 25%–40% Rotor losses, 15%–25% Strayload losses, 10% . Using Table 1 experiment, the results for initial energy consumption computation for the irrigation system to fill the tank are 3.73kW-hr/day. To maintain 500 liters of water as mentioned earlier, the energy requirements for the system is 1.24kW-hr/day.

V. DISCUSSION AND ANALYSIS OF RESULTS

The testing was performed in the irrigation system at Smart Farm for Tomato situated at Sitio Ugat, Brgy. Maybangcal, Morong, Rizal as seen in figure 2a. The previous system were used conventional or manual switching system and it used a 1hp single phase induction motor. Figure 10 show the line graph of current consumption for both MPERIS and conventional system. It is notice that conventional system required high amount of current for starting process for single phase induction motor. It has also an average current consumption of 8.1 amperes, which is very high compare with MPERIS. Using Variable Frequency Drive (VFD) for this system made possible to use three phase induction motor and implementation of fuzzy logic to maximize the percentage of energy savings. It is possible even if the supply coming from photovoltaic cell (solar panel), the system can manipulate the starting revolution per minute (rpm) of motor by gradual increasing of frequency (Hz) from 0Hz to 60Hz induced in three phase induction motor, since the rpm of motor are direct proportionally related to frequency, the current requirements are resulting into very minimal value. It is also noticed that the current consumption of MPIRES had an average of 2.0 ampere, while the Conventional system had an average of 8.1 amperes, this can be seen on Table 4. The graph also show that the out MPIRES are in linear while conventional system are non-linear.

[Table 4: % Savings and Current Consumption of MPSEIS and Conventional System]

<table>
<thead>
<tr>
<th>Times (s)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
<th>40</th>
<th>45</th>
<th>50</th>
<th>55</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMSEIS</td>
<td>0</td>
<td>2.2</td>
<td>2.1</td>
<td>1.9</td>
<td>1.8</td>
<td>1.7</td>
<td>1.9</td>
<td>2.1</td>
<td>2.2</td>
<td>2.2</td>
<td>1.8</td>
<td>2.1</td>
<td>2.2</td>
</tr>
<tr>
<td>Conventional</td>
<td>0</td>
<td>15</td>
<td>12</td>
<td>9</td>
<td>6.8</td>
<td>6</td>
<td>6.5</td>
<td>6.8</td>
<td>7</td>
<td>7.3</td>
<td>6.5</td>
<td>6.9</td>
<td>7.1</td>
</tr>
<tr>
<td>% Savings</td>
<td>0</td>
<td>85.3</td>
<td>82.5</td>
<td>78.9</td>
<td>73.5</td>
<td>71.7</td>
<td>70.8</td>
<td>70.6</td>
<td>70.0</td>
<td>69.9</td>
<td>72.3</td>
<td>69.6</td>
<td>69.0</td>
</tr>
</tbody>
</table>

[Figure 10: Line graph of current consumption for PMSEIS and Convention System]
Percentage current are calculated based on the Equation 9, where in the average current savings was computed equal to 73.7% compare from the conventional system.

\[
\% \text{savings} = \frac{\text{Con. Current} - \text{MPERIS Current}}{\text{Con. Current}} \times 100 \tag{9}
\]

Figure 12 shows the line graph comparison of percentage efficiency of the two systems. The MPERIS has an average efficiency of 90.55 percent and conventional system has an average efficiency of 59.98 percent. MPERIS has an advantage of almost 30.57 percent of efficiency for the whole system.

VI. CONCLUSION AND RECOMMENDATIONS

Using of VFD and MCU with the implementation of fuzzy logic-based motor speed controller into Irrigation system was obviously successful. Results showed that the fuzzy controller is significantly better compared to the conventional controller in terms of handling load variations.

It is also appreciate the use of fuzzy logic for enhancing the capabilities of the MCU in providing intelligent automation process. Results showed that the developed controller is accurate, reliable and robust by providing a percentage savings of current usage which is 73.7 percent.

ACKNOWLEDGMENT

The authors would like to acknowledge University of Rizal System-Morong, De La Salle University-Manila and the Engineering Research and Development for Technology (ERDT) of the Department of Science and Technology (DOST) for the research support and funding.

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