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Monitoring System for Organic Fertilizer Plant Controller Using Solar Energy

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Abstract. In this applied research, a solar energy powered process control monitoring system of inorganic fertilizer plant with capacity of 300 liters has been developed. The process control system consists of PLC with solar energy panel as its power source and a monitoring process system. The monitoring process system includes a Raspberry Pi minicomputer, an LCD touchscreen, level shifter converters, Arduino Nano, RS485 modules, four analog sensors, and one digital sensor. This system works by collecting temperature, humidity, and gas concentrations data and controlling the heater, exhaust fan, and aerator to maintain desired processing conditions. DHT-22 digital sensor measures temperature and humidity, pH probe analog sensor measures pH values, MQ-4, MQ-7 and MiCS-2714 measures methane, carbon monoxide, and nitrogen dioxide gases respectively. Analog output sensor is read by PLC's analog to digital converter while digital output sensor is read by 1-wire bus by Arduino. The collected data is send over RS485 to Raspberry Pi. The plant temperature is set constant at 40°C. The heater is turned on at temperature of $\leq 38^{\circ}\text{C}$, when temperature reach $\leq 42^{\circ}\text{C}$ the aerator, exhaust fan, and mixer will be on and will be switched off all together at 40°C. The temperature, humidity and PH are set as the reference of the control process.

1. Foreword

Domestic waste problem has known to be a classical challenge in many places ranging from big cities to villages. The increasing number in population and urbanization, inefficient waste process as well as human behaviour are the main contributors for the problem. One of the popular solution to reduce the end product of domestic waste is to turn the waste into organic fertilizer through composting process. The aim of this research is to improve the previously built organic fertilizer plant monitoring system with an Arduino Nano as monitoring device, a PLC as controller and incorporating solar energy as electric power source by using Photovoltaic solar cell. This research brings four benefits to the overall system. First is controlling using PLC, second is to be able to monitor the making of the organic fertilizer, third is to use renewable energy source, and fourth is to be used as a learning module for process control system teaching in universities.



2. Literature Study

2.1. Organic Fertilizer

Organic fertilizers are fertilizers that are mostly or wholly composed of organic materials derived from crop residues, and or animals that have undergone engineering in the form of solid or liquid used to supply organic materials, possessing physical, chemical, and biological properties of soil (Regulation of the Minister of Agriculture, No.28/permentan/sr.130/5/2009 in 2009 [1]. According to J.H.Crawford (2003), compost is the result of incomplete and artificially accelerated decomposition by populations of various microbes in warm, humid, aerobic or aerobic environments (Nyoman P. Aryantha et al, 2010) [2]. To produce compost, one need to regulate and control the natural process so that the compost can be formed faster. This can be done by making a balanced mixture of ingredients, adequate water supply, aeration set, and the addition of the activator. According to (Nyoman P. Aryantha, et al, 2010) [2], the quality of the compost is good if: 1. Colored dark brown to black similar to the color of the soil, 2. Insoluble in water, 3. C / N ratio of 20-20, depending on the raw material and degree of humification, 4. It works well if applied, 5. Its temperature is more or less the same as ambient temperature, 6. No smell.

2.1.1. Arduino nano

Arduino nano is a small microcontroller development board that contains a complete computer in a compact size, it has an Atmega328 at its heart. The ATmega328, has a memory of 32KB which 0.5KB is used as a bootloader. It has 2KB SRAM and 1KB EEPROM. The pins are divided into 14 digital pins, 6 analog pins and several other pins. Among 14 digital pins available, they can be used as inputs or outputs at 5V operating voltage. Each pin can source and sink current of up to 40mA and has an internal resistance pull-up of 20k Ω to 50k Ω (inactive under default condition). Some pins have special functions, namely, pin 0 (RX) and 1 (TX) are used for serial data and pin 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK) are used as SPI communication (Margolis 2011). The Arduino nano has 6 analog inputs labeled A0-A5. Arduino nano is programmed using the Arduino IDE that uses the C or C++ based programming language. Programs that have been compiled can be directly uploaded to Arduino nano using a USB connection [3]. The Arduino Nano board can be seen in Figure 1.

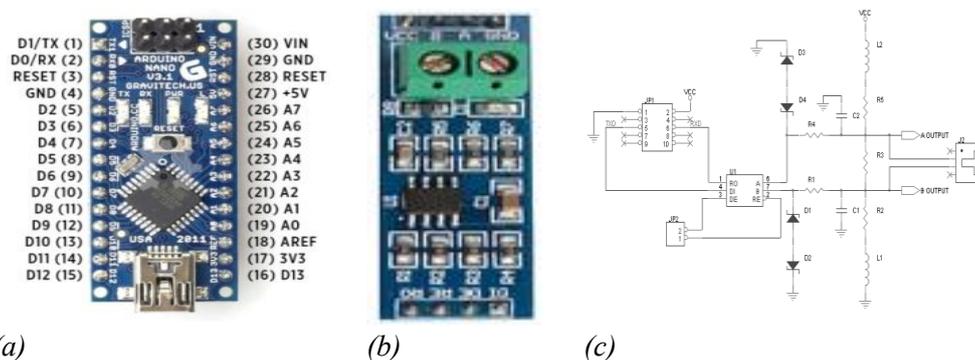


Figure 1. (a) Pins Layout of Arduino Nano (b) RS485 Module (c) RS485 circuit

Communication to and from the Arduino Nano microcontroller uses RS485 which is one of the half duplex communication modules, serially. Half duplex means being able to send or receive data on the same path, alternating (one direction at a time). RS485 module has 8 pins namely Vcc, GND, A & B, DE, RE, DI, and RO. The advantages of using RS485 is to be able to connect 32 slaves (modbus mode), with data speed reaching 1 mbps and a maximum range of 1200 meters [4].

2.1.2. Raspberry Pi Minicomputer

Raspberry Pi is a Single Board Computer (SBC). It has two models, model A and model B. Raspberry Pi Model B has 512 MB of memory and also equipped with Ethernet port.

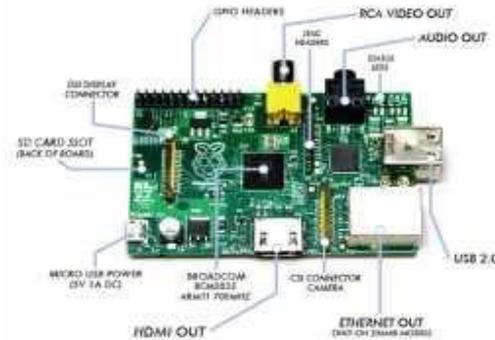


Figure 2. Raspberry Pi Model B

The Raspberry Pi design is based on SoC (System-on-a-chip) from Broadcom, the BCM2835. It has embedded the ARM1176JZF-S processor with 700MHz. Data storage is designed to rely on an SD memory card for booting and long-term storage [5] [6] [7]. Python is the official language of high-level programming in Raspberry Pi. The word "Pi" in Raspberry Pi refers to "Python, where Python programming is directly programmed in the Raspberry Pi operating system. Python is interpreter, interactive, object oriented and can operate at almost any platform, such as UNIX, Mac, Windows, OS/2 or something else. Python is a freeware programming language or free device, complete with source code, debugger, profiler, system functions, GUI and database [8].

2.2. Sensor

The utilization of gas sensors serves to measure pollutant gases during the making process of the fertilizer in the reactor. The sensors are: (1) DHT22 sensor is selected because it can measure the temperature and humidity of the surrounding air. It has a wide measurement range of 0-100 % for humidity and -40 to 125°C for temperature, has digital output (single-bus) with high accuracy and precision in terms of measurement [9]. (2) MQ4 sensor has the ability to detect the concentration of methane (CH) in the air. The detection range 300-10000 ppm and requires a power supply of 5V. (3) The MQ-7 sensor is used for detecting Carbon Monoxide (CO) gas. It operates at temperatures from -10 to 50°C and consumes less than 150 mA of current at 5V. The MQ-7 gas detection range spans from 10-1000 ppm. (4) MiCS-2714 is used for nitrogen gas. (5) A soil pH sensor is specialized sensor to detect soil acidity or basicity. The pH scale that can be measured by the sensor ranges from 3.5 to 8. It works on dc voltage of 5V with soil pH linearity coefficient of 0.9962.

2.3. Programmable Logic Control (PLC)

According to the National Manufacturers Association (NEMA) ICS3-1979 part ICS3-304, Programmable Logic Controller (PLC) operates digitally, has a memory that can store instructions to perform special functions such as logic functions, timers, calculations and arithmetic to control through analog or digital input and output modules. It can communicate with a computer using a data cable with RS485 communication module. This PLC is using CX-Programmer software which is part of CX-One software suite. By using this software, it can program various PLCs made by Omron and has a built-in simulation features without having to connect with a PLC. It can simulate a ladder that is made and can be connected to the Omron PLC HMI that has been created using CX-Designer. CX-One can run on Windows XP (Service Pack 3 or higher, 32-bit version), Windows Vista (32-bit / 64-bit version) or Windows 7 (32-bit / 64-bit version) [10] [11].

2.4. Solar Power System using PV solar cell

The solar power system consists of: 1) **Solar Charge Controller** that can be functioned as: 1) **Charging mode** to charge the battery; 2) **Operation mode** to use battery onto the load. While in Charging Mode Solar Charge Controller: In charging mode, generally the battery is charged with three stage charging method: 1) Bulk phase is the phase in which the battery is charged according to the setup voltage (bulk-between 14.4V to 14.6V) and the current is taken at its maximum point; 2) Absorption phase is the phase of maintaining the battery voltage in accordance with the bulk voltage for 1 hour and the current flow decreases until the capacity is reached; 3) The float phase is to keep the battery in the float voltage ranging from 13.4V to 13.7V. 2) **Power Inverters** is an electronic device that changes the current and power of the battery (DC) into a household-ready AC voltage that is suitable for backup electricity. 3) The VRLA battery (Valve-Regulated Lead-Acid battery) has a floating voltage of about 2.35 volts per cell at 25°C. The design of rectangular cells allows the valve to be set to operate at 1 or 2 psi, but the round spiral cells with external metal container has a valve that can be adjusted with a pressure of 40 psi [12] [13].

3. Research Method

3.1. Monitoring System Block Diagram

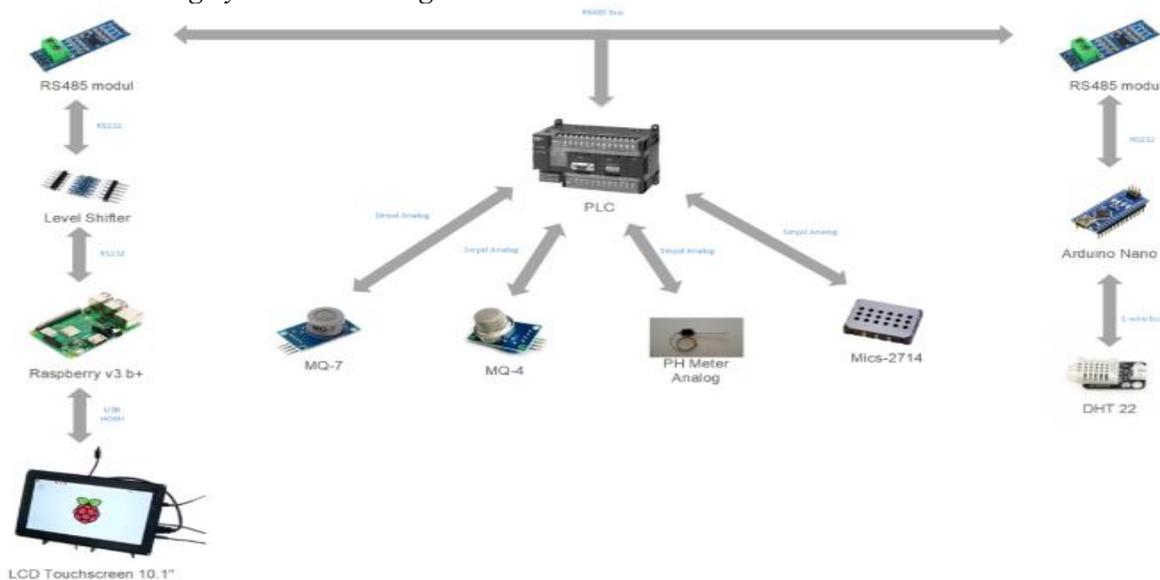


Figure3. Monitoring system

3.2. Solar Power System and Tracking Circuit

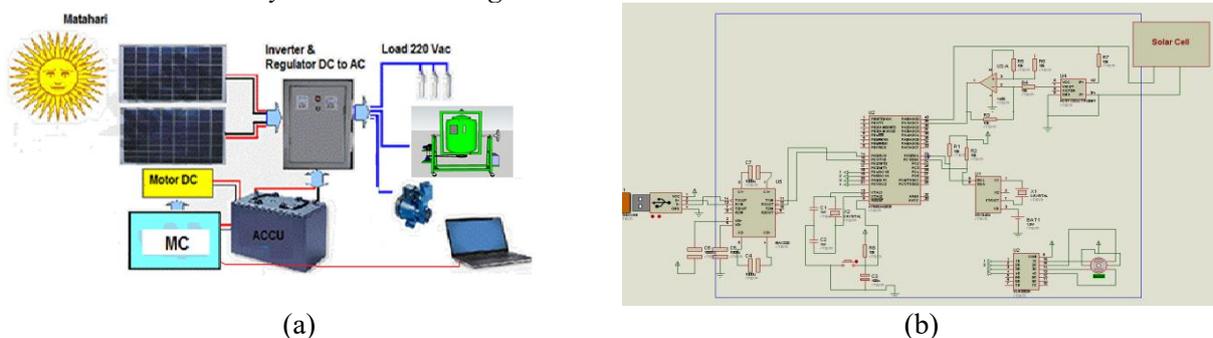


Figure 4. (a) Solar Power System (b) Solar cell tracking circuit

4. Results and Discussions

Programmable Logic Control (PLC) receives an analog data sensor signal read by the ADC of the PLC. Arduino nano is used as a digital signal data communication device from MQ4, MQ7, pH, MiCS 2714 and DHT22 sensors, all the data is sent using RS485 to Raspberry Pi. The Raspberry Pi acts as the monitoring role. Setting point temperature is determined as $\pm 40^{\circ}\text{C}$ if the temperature is $\leq 38^{\circ}\text{C}$. The heater then turned on to raise the chamber temperature of the plant to reach 40°C then it turned off. If the temperature is $\geq 42^{\circ}\text{C}$ then the exhaust fan works to remove excess heat from the plant chamber. At the same time, the aerator works by spraying water to cool down the chamber to reach a temperature of 40°C which then stopped the exhaust fan and aerator all together.

Figure 6 shows the solar cell tracking circuit that is connected to the PV solar cell electric power system. It produces a direct electric current (DC) that is converted to AC voltage. This system consists of one solar charge control and one 1000Watt 220V AC inverter. The amount of electricity produced by the inverter is measured in watts (W). This system uses two 12V batteries at 100Ah (Ampere hour). A stepped motor with operating voltage of 36V is used as rotator for the PV solar cell panel frame. Assuming a power inverter efficiency of 90%, around 1500 Watts of power can be generated.

4.1. PLC Ladder Programs

The design of this program consists of: (1) Ladder Diagram Design that consists of 5 inputs and 4 outputs controlled by PLC. The ladder diagram consists of the logic input on the left and the logic output on the right. The combination of logic input and logic output forms a rung and as many as 29 rungs in accordance to the control description. The symbol of the input and output equipment: (a) Normally open, (b) Normally closed, (c) Output coil, (c) Timer, and (d) Counter. To run the ladder program that has been created, the CX-programmer software version 9.0 is used. Flowchart of the ladder diagram programming is shown in Figure 5.

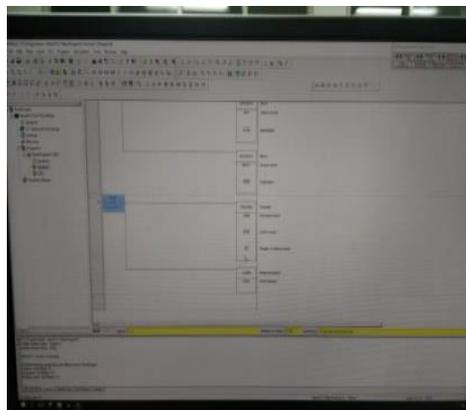


Figure 5. Test display of CX-Programmer V 9.0

The results of the ladder diagram test on the PLC are as follows:

4.1.1. Rung 0 to Rung 4:

Rung 0: serves to turn on the controller tool in the plant by activating PB ON (0.00) at a value of 1, then relay will be ON (200.00) and will be locked. Rung 1: act to turn on sensors such as temperature (Q: 100.00), pH indicator (Q: 100.01) and humidity (Q: 100.03) which are turned on by an internal Relay (200.00). Rung 2: functions to turn on and turn off the normal state of the light that is controlled by Time on << 38 (T000) and Time on >> 42 (T0001). Input from internal Relay (200.00). Rung 3: serves to receive input from the temperature sensor to decide whether the temperature is << 38 (I: 0.02), Time << 38 will be on (T0000) at the input value of 1 then internal Relay << 38 (200.01) will be locked, because of input from << 38 (I: 0.02). Rung 4: function to activate the Heater (Q: 100.02) and turn on Time << 38 to turn off the Heater. T0000 will be on if there is an input value of 1.

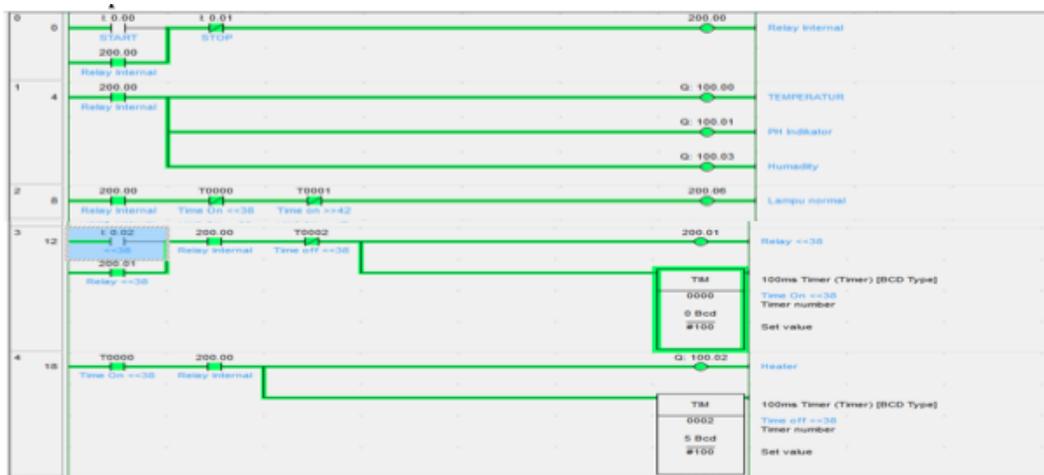


Figure 6. Ladder Rung 0 to 4

4.1.2. Rung 5 to Rung 9:

Rung 5: Functioning when the temperature inside the reactor plant exceeds ≥ 42 (I: 0.03) then turn on Time $\gg 42$ (T0001) and Relay $\gg 42$ (200.02) to lock Time. Temperature ≥ 42 (I: 0.03) will be on if there is input value of 1. Rung6: Address T0001 serves to activate Fan (Q: 100.04), Aerator (Q: 100.05), Motor (Q: 100.06) and Time off $\gg 42$ (T0003). Time functions as a switch to switched off if the temperature at the reactor plant is = 40 (normal). Rung 7: Functioning as a receiver output from the Indicator pH sensor output (D5), P_1s generates a clock with a 1 second period. Rung 8: Set pH points (D6) functioning as a giver of the output given by the pH sensor. Reset relay of pH (200.10) serves to decide the output of the pH sensor. Reset relay will work if D6 has reached the limit when set. Rung 9: Function as the receiver output from the Humidity (D7) sensor output P_1s, generates a clock with a period of 1 second.

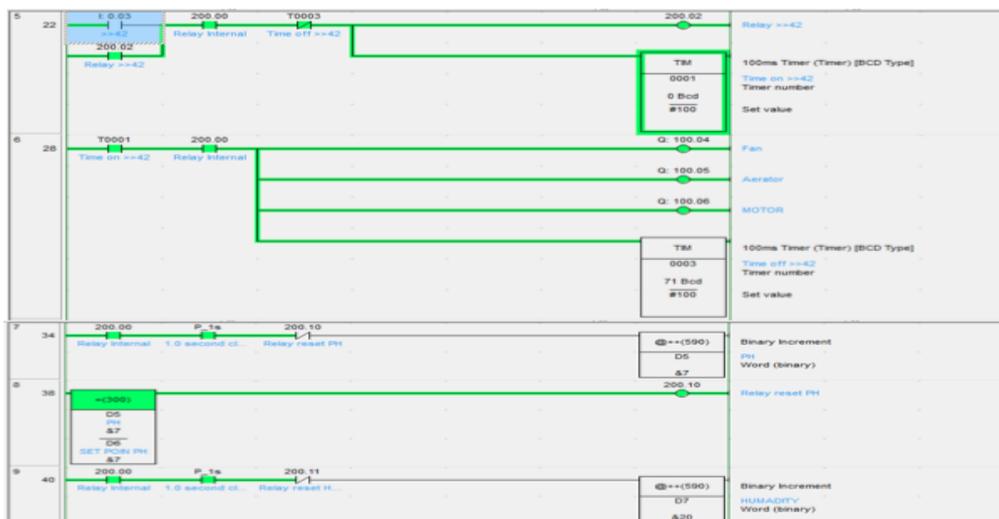


Figure 7. Ladder Rung 5 to 9

4.1.3. Rung 10 to Rung 14:

Rung 10: Set points of Humidity (D8) function as the giver of the output given by the humidity sensor. Reset relay humidity (200.11) serves to decide the output of the Humidity sensor. Reset relay will work if D8 has reached the limit when set. Rung 11: Works to turn on MQ-04 by activating PB

ON (I: 0.04) at a value of 1, then Relay MQ-04 ON (200.03) and will be locked. Relay reset MQ-04 (200.04) functions as a readout breaker from the sensor output. Rung 12: Relay MQ-04 (200.03) ON then the actuator MQ-04 (D0) will receive the output value from the MQ-04 sensor. P_1s generates a clock with a period of 1 second. Rung 13: Set points MQ-04 (D1) serves as a delimiter of the output given by the sensor MQ-04. Reset relay MQ-04 (200.04) serves to decide the output of the MQ-04 sensor. Reset relay will work if D1 has reached the limit when set. Rung14: Function to turn on MQ-07 by activating PB ON (I: 0.05) at a value of 1, then Relay MQ-07 ON (200.05) and will be locked.

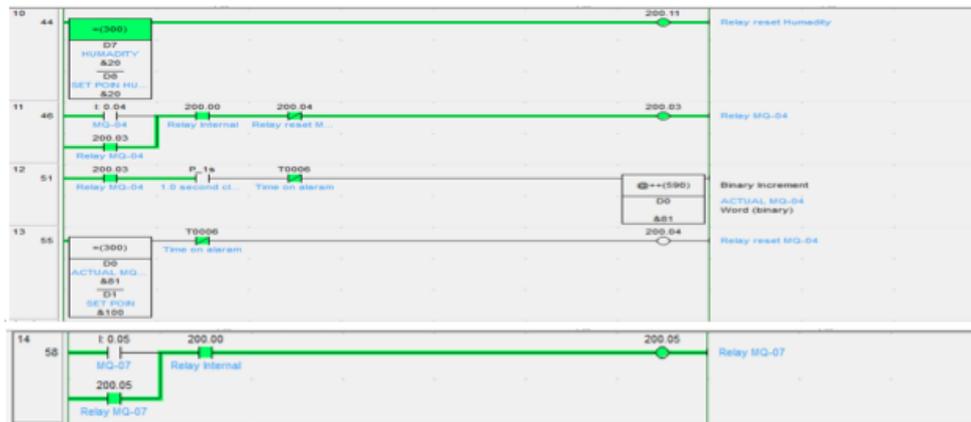


Figure 8. Ladder Rung 10 to 14

4.1.4. Rung 15 to Rung 19:

Rung 15: Relay MQ-07 (200.05) ON it will provide output from the MQ-07 sensor input which is displayed on the MQ-07 actuator. P_1s generates a clock with a 1 second period; Rung 16: Serves to turn on the Mi-CS by activating PB ON (I: 0.06) at a value of 1, then Relay Mi-CS ON (200.08) and will lock. Reset Relay (200.09) serves as the output breaker of the input sensor. Rung 17: Mi-CS Relay (200.08) ON it will give the input output from the Mi-CS sensor which will be displayed on the Mi-CS (D3) actuator. P_1s generates a clock with a 1 second period; Rung 18: Mi-CS set point (D3) serves as a delimiter of the output given by the Mi-CS sensor. Relay reset Mi-CS (200.09) serves to decide the output of the Mi-CS sensor. The reset reset will work if D4 has reached the limit when set. Rung 19: Function to reset the values provided by the sensors if you want to recalculate by activating PB Reset ON (I: 0.07) at a value of 1.

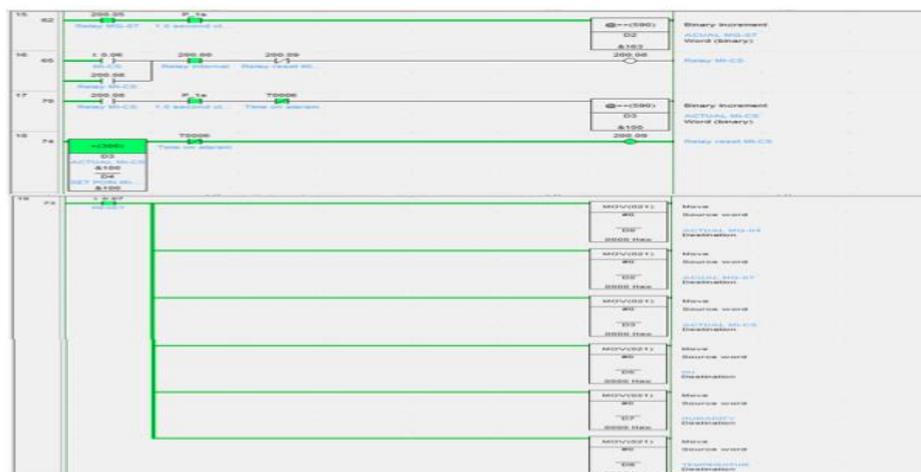


Figure9. Ladder Rung 15 to 19

4.1.5. Rung 20 to Rung 24:

Rung 20: Relay temperature rises (200.14) serves to see the input of the temperature sensor when the temperature rises which is displayed on D9. The temperature rise will work if there is an input value of 1.) P_1s generating a clock with a period of 1 second. Rung 21: Temperature rises (D10) serves as the limit of the output given by the temperature sensor. The relay off temperature rises (200.12) serves to break the output of the Mi-CS sensor. The relay off temperature rises will work if the D9 has reached the limit when set. Rung 22: When T0001 is ON it activates the Relay temperature up (200.14) and it will be locked. Relay off temperature rises (200.12) serves as a breaker Relay (200.14). Rung 23: Serves as a reader of temperature 40 (normal). When the temperature is normal (I: 0.08) ON value is given a value of 1, then the Temperature D9 value will show a temperature value of 40. A value of 40 can change depending on how it is set in the *source word*. It will give input values on the temperature display (D9) when the temperature drops P_1s generates a clock with a second period.



Figure10. Ladder Rung 20 to 24

4.1.6. Rung 25 to Rung 29:

Rung 25: Temperature drops (D11) serves as the limit of the output given by the temperature sensor. The relay off temperature rises (200.12) serves to break the output of the Mi-CS2714 sensor. Relay off temperature rises will work if D9 has reached the limit when set. Rung 26: When T0000 is ON it will activate the Relay temperature down (200.15) and it will be locked. Normal NC (I: 0.08) and NC Relay temperatures drop (200.13) function as breakers to turn off the temperature relay down (200.15). Rung 27: When relay MQ-04 (200.04) and relay Mi-CS (200.09) ON, it will turn on Alarm Relay (200.07) and it will be locked. Rung 28: When Relay alarm is active it will turn on Alarm (Q: 100.07). An active alarm indicates that the plant fertilizer at the plant is ready to be lifted.



Figure11. Ladder Rung 25 to 29

The results of testing the input on the PLC in Rung 0 to Rung 29 can be seen in Table 1 while the results of the output of the ladder program testing on the PLC in Rung 0 to Rung 29 can be observed in Table 2.

Table 1. Test results of PLC's inputs

No	Input Address	Equipment	Indicator on the PLC	Note
1	00.0	PB Start	On	Working
2	00.1	PB Stop	On	Working
3	00.2	≤ 38	On	Working
4	00.3	≥ 42	On	Working
5	00.4	MQ-04	On	Working
6	00.5	MQ-07	On	Working
7	00.6	Mi-CS	On	Working
8	00.7	Reset	On	Working

Table 2. Test results of PLC's outputs

No	Input Address	Equipment	Indicator on the PLC	Note
1	100.00	Temperature	On	Working
2	100.01	pH Indicator	On	Working
3	100.02	Heater	On	Working
4	100.03	Humidity	On	Working
5	100.04	Fan	On	Working
6	100.05	Aerator	On	Working
7	100.06	Motor	On	Working
8	100.07	Alarm	On	Working

Table 1 shows the relation and condition of the equipment at the time of input testing on the PLC. Table 2 shows the condition on the PLC output in which the output section is equipped with indicator light to give a sign that the equipment and sensor that are being controlled work.



Figure 12. Time diagram

Figure 12 shows the time diagram of the system on the sensors control circuit with the PLC as described on the control principle on the reactor plant operation.

4.2. Solar Cell Photovoltaic Energy

Figure 13 shows the top side image of voltage graph derived from PV solar cell while the bottom side of the image shows of the graph of the inverter.

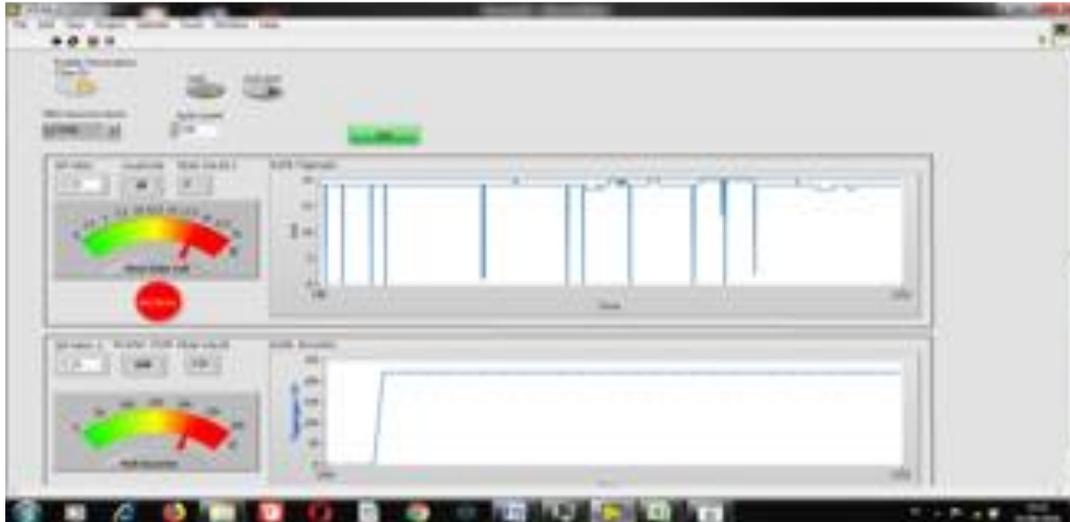


Figure13. Voltage display of upper graph: Solar cell and down graph: Inverter

4.3. Sensors Reading

Figure 15 is a form of display of dummy measurement results from temperature and humidity sensors using a DHT22 sensor, acidic, neutral and alkaline levels using a pH meter, carbon monoxide (CO) gas content using MQ7 sensor and methane gas content using MQ4 sensor. The temperature, moisture and gases works based on voltage changes according to the amount of environmental conditions incident to the sensor surface.

No.	Waktu	Tanggal	Suhu/Temp	Kelembaban	PH	Gas CH4	Gas CO	Gas MQ2
1	15:05	17 Jul 2018	34	20	7	70	80	43
2	15:06	18 Jul 2018	36	36	4	70	80	48
3	16:01	14 Jul 2018	45	69	5	100	34	54
4	16:02	15 Jul 2018	45	57	5	34	26	54

Figure 15. Result of sensor and substance display test

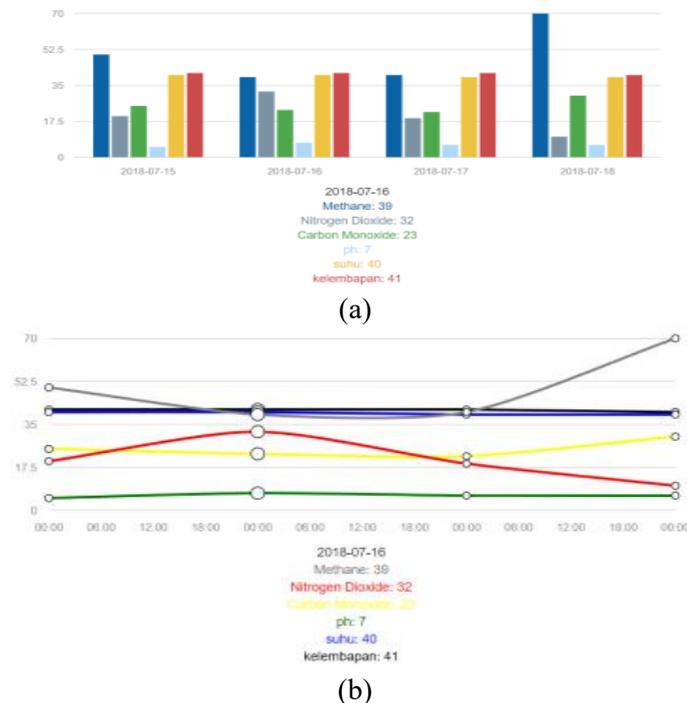


Figure 16. Sensors test results (a) Bar graph (b) Line graph

By using the Arduino internal ADC reading algorithm, the analog values can be converted to digital data. Arduino nano includes several parameters and registers that are set to perform this task. There is a delay from the internal ADC control on the microcontroller used for the conversion process. The process is arranged based on the ADC configuration of the designed clocking system. To find out if the conversion process is complete, one can read the ADCSRA register on the 4th bit. This bit will be '0' (low) when the ADC conversion is complete and will be '1' (high), if the conversion process is still in progress. The result is then stored in the ADCH register for the MSB bits (8 bit and 9 bit) while the lower bits (LSB) is stored in the ADCL register which includes the bit 0 to 7 so that the data can be retrieved from the register. Next the 4th bit ADCSRA bit is manually toggled to 'high' as mark on the internal controller ADC that the ADC data has been read. In Arduino programming, the ADC reading is implemented with a simple command of *analog read (analog input)* so that the parameter settings in ADC's registers have been done automatically on the Arduino Nano. Therefore, the value of the environmental conditions and gas content contained in the area of the reactor plant will be read until it reaches the value that exists in the reactor plant. To know the volume of gas sucked, one can use the formula of: $V = A \cdot \omega \cdot r \cdot t$, where: V = volume (plant) of gas, A = cross-sectional area, ω = suction rotating speed, r = cross section radius, and t = time.



Figure17. C/N ratio display

5. Conclusion

The conclusions of the research are as follows. First, the test result of the ladder program on the PLC is running in accordance to the description as shown by the presence of green colors on the diagram lines. Second, all the inputs and outputs functioned well according to the input and output codes given. Third, sensors monitoring program is successfully tested by using dummy method and is ready to be applied to the organic fertilizer processing plant. Fourth, the monitoring program to display the voltage values in the solar power system runs well and able to display graphs and voltages of the solar cell and inverter. Fifth, the solar tracking program that is govern the integrated rotator in the solar cell PV runs well. Our suggestions in this applied research is that it requires sufficient time to maximize the performance of the tool and collecting and monitoring data in real-time. Support from relevant government institutions is also really essential for further development.

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