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Design of an automatic common water hyacinth flattening machine with an off-grid solar energy system

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Abstract

Transforming common water hyacinths into handicrafts is a viable business opportunity in several regions across Indonesia. One of the crucial processing stages in producing these handicrafts is flattening, which reduces the plant material to approximately 0.2 mm in thickness to ensure optimal weaving quality. The objective of this research is to design an automatic water hyacinth harvesting machine that uses an off-grid solar power plant as its primary energy source. The automation system on this machine uses a Programmable Logic Controller (PLC) as the control system and Supervisory Control and Data Acquisition (SCADA) as the interface and monitoring system. The designed water hyacinth flattening machine increases production capacity to 834 grams in 15 minutes. The size of flattened water hyacinths was 0.2 mm, following the flattening roller setting. The machine's average power consumption is 249 W, which the solar power plant system can supply for approximately 1.5 hours.

Keywords:

Common water hyacinths, flattening machine, PLC, SCADA, solar power plant

1 Introduction

Common water hyacinths grow invasively in swamps and lakes, for example, at Rawa Pening, where their populations are abundant. Yet, common water hyacinths are considered weeds because of their adverse effects on water quality, dissolved oxygen, fish production, and water transportation routes [1], [2], [3], [4]. However, some research indicates that plants can positively affect the community economy by being transformed into woven handicrafts [1], [5], [6], [7].

Capitalizing on and transforming common water hyacinths into handicrafts has proven to be a reliable business opportunity in several regions across Indonesia [8], [9], [10]. Creating handicrafts from common water hyacinth involves several processing steps, such as flattening. Artisans flatten the plant using manual rollers, making the process deeply dependent on the availability of human labor [8], [11].

The implementation of automatic systems for flattening processes in industrial sectors is highly beneficial. It improves labor and time efficiency, enhances product quality, and minimizes potential errors, thereby significantly increasing production levels. These systems are essential for modern industries aiming to optimize their operations and maintain a competitive edge in the market [12], [13], [14], [15], [16]. Accordingly, installed automatic systems must demonstrate

reliability in addressing detrimental effects on the production process. Previous studies have found that Programmable Logic Controllers (PLCs) are widely implemented in industries after being tested as reliable and capable of accelerating the production process, and demanding simple maintenance [17], [18], [19].

PLC is a specialized digital computer used to automate industrial processes, such as controlling machinery on factory assembly lines, amusement rides, or light fixtures. PLCs are designed to handle multiple inputs and outputs, and they can receive and transmit analog, digital, and discrete signals [18], [20], [21], [22]. PLCs operate on a digital system and are programmed sequentially using a ladder diagram. Programming PLCs allows engineers to modify programs to meet system requirements. Designing the programs is simulated through software, and the simulation results can be directly applied to hardware [23], [24], [25]. PLC runs with a low power supply in the system, controlling and minimizing larger system failures [26].

This research employs PLC as a controller to operate a single-phase electric motor that drives conveyors and rollers. According to a previous study, the Omron CP-series PLC can effectively control a single-phase electric motor, enabling operators to perform tasks more efficiently [27], [28]. PLC can also be installed to process input signals from proximity sensors and limit switches. Sensors serve as system inputs in automated machines, converting physical quantities into electrical signals. These signals are then processed by PLCs to control and monitor various industrial processes. PLCs also enable real-time automatic monitoring and control. [29], [30], [31], [32], [33]. This research uses proximity sensors to detect work objects, i.e., common water hyacinths, and employs limit switches as automatic switches.

Off-grid solar power plant systems serve as the primary power source for the standard water hyacinth flattening machine, thereby optimizing electrical power for the automatic flattening machine used in producing woven handicrafts. Solar farms significantly reduce greenhouse gas emissions and dependence on fossil fuels, contributing to the mitigation of global climate change [34], [35], [36]. Solar energy provides a reliable source of electricity in remote and off-grid areas [37]. Additionally, solar farms are a critical component of Indonesia's strategy to transition to renewable energy and mitigate climate change. By addressing policy, financial, and technical challenges, and leveraging the country's solar potential, Indonesia can significantly reduce its GHG emissions and achieve its long-term climate goals [38], [39], [40].

Regarding its objectives, this research aims to design an automatic standard water hyacinth machine powered by an off-grid solar power plant. This machine is designed to flatten common water hyacinths as effectively as operators require and to increase the production capacity of flattened water hyacinths relative to conventional methods. The solar power plant system is expected to supply the power needed for this machine, making this research result an innovation in energy-saving machines for the production of common water hyacinth woven handicrafts.

2 Research methods

This research employed an experimental approach and an engineering design to develop an automatic-control-based common water hyacinth flattening machine powered by a solar power plant. A literature review was conducted to examine the characteristics of common water hyacinths, the flattening process, the operating principles of automatic machines, PLC-based control systems, Supervisory Control and Data Acquisition (SCADA) monitoring systems, and solar power plant systems as a renewable energy source. The understandings were then used to design and implement the system. Testing the flattening machine and power supply was conducted at the Electrical Laboratory, the Electrical Engineering Department, Politeknik Negeri Semarang.

This research also designed mechanical and electrical components and a power supply for the standard water hyacinth

flattening machine. The designed flattening machine was adapted to the needs of industries that produce handicrafts from common water hyacinths. The machine was expected to flatten common water hyacinths effectively and efficiently.

Fig. 1 demonstrates the design of the standard water hyacinth flattening machine, which is composed of (1) an indicator panel, (2) a conveyor, (3) a proximity sensor, (4) a box PB (push button) and a selector panel, (5) a control panel, (6) a gearbox, and (7) a single-phase electric motor. An indicator light and an LCD (liquid crystal display) were installed on the indicator panel, which was designed as a cover-like unit to conceal the components of the flattening machine. The standard water hyacinth flattening machine was divided into three parts: mechanical design, electrical design, and off-grid solar power plant system design.

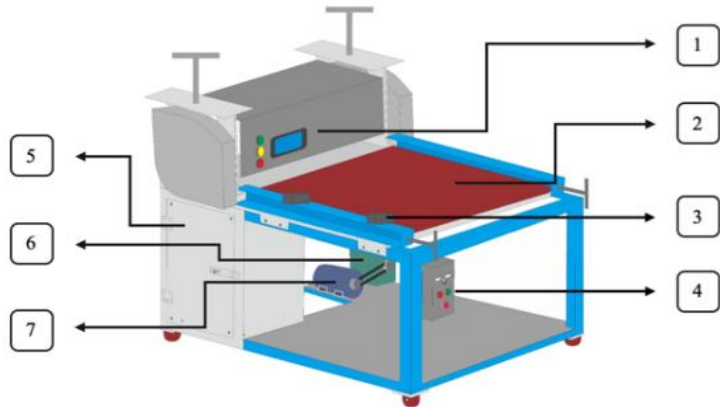


Fig. 1. Common water hyacinth flattening machine design

2.1 Mechanical designing

Mechanical design encompassed the design of the machine frame, conveyor rollers, and flattening rollers. The machine support frame was constructed from hollow iron measuring 1 m × 0.8 m × 0.5 m. A control panel box of 0.5 m × 0.4 m × 0.2 m was installed on the back of the support frame. The control panel box was the space where the control device, electrical components, and wiring were put in, and was the system's electrical power distribution center [41]. Fig. 2 exhibits the support frame and control panel box designs.

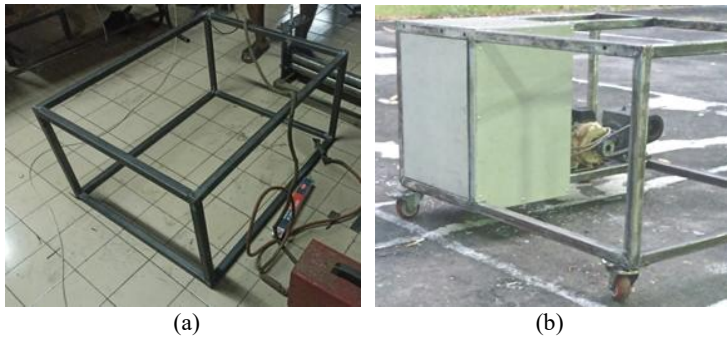


Fig. 2. (a) Machine support frame; and (b) Control panel box

Mechanical design also included the Development of a drive system to move workpieces. The drive system was a conveyor with three rollers, as indicated in Fig. 3(a). The three rollers were arranged horizontally in parallel, interspersed with two hollow irons between them. A pillow block and bearing were installed at the end of one of the rollers to support the machine shaft rotation. In addition, rollers also functioned as flattening or pressing units. Flattening unit rollers were installed in parallel, as pointed out in Fig. 3(b). The distance between the rollers was adjustable based on the thickness of the common water hyacinths to be flattened. The flattening unit was expected to flatten the plants to 0.2 mm.

A single-phase electric motor was applied in this research because of its efficiency in energy utilization and reliability for industrial machines [42], [43]. The specifications for the electric motor deployed specified a nominal current of 2.6 A, a voltage of 220 V, a rotational speed of 1500 rpm, and a power of 0.25 HP.



Fig. 3. (a) Conveyor frame; and (b) roller

The electric motor served as the system's main driver. The generated power would be transmitted to the pulley and gearbox, then to the conveyor belt and flattening rollers.

2.2 Electrical designing

Electrical designing encompasses the design of control and monitoring systems. The system's flowchart is presented in Fig. 4. The automatic flattening machine in this study could be operated either manually via a Push Button (PB) or automatically via proximity sensors.

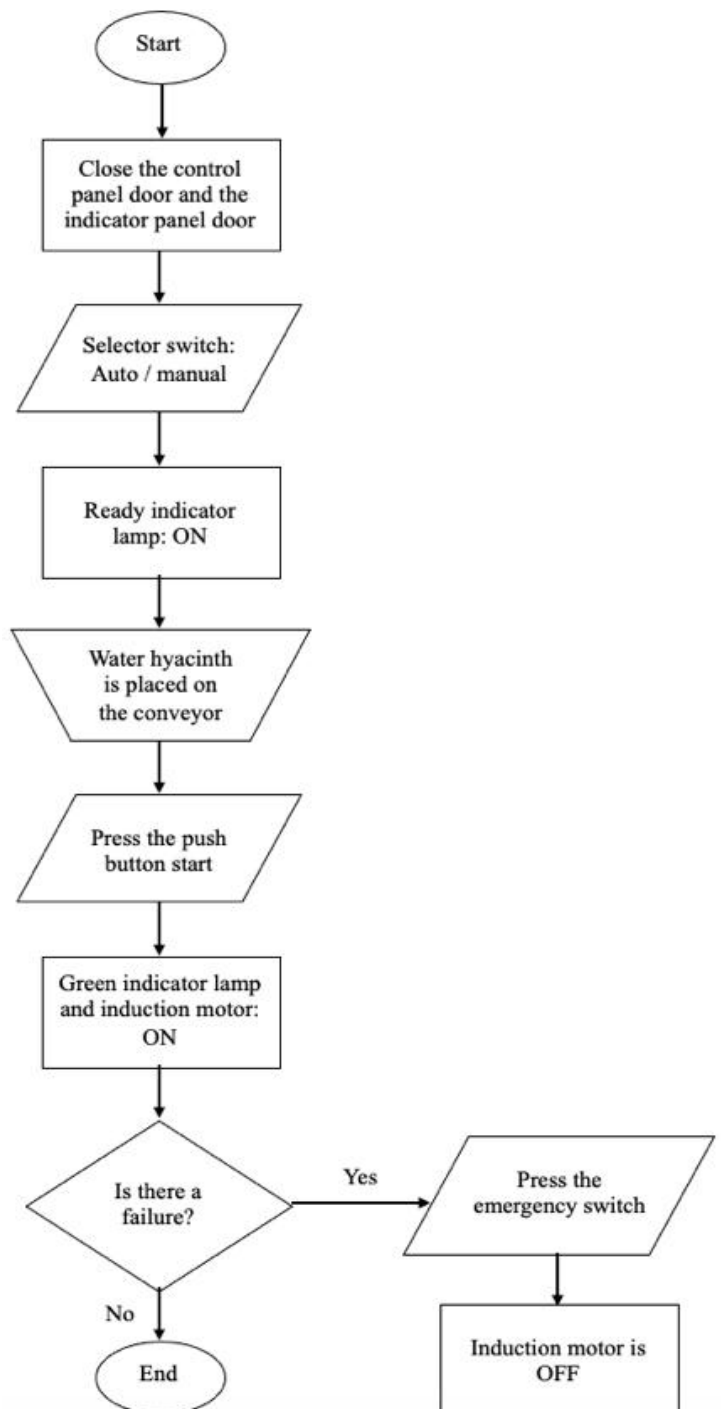


Fig. 4. System flowchart

The initial step was to close the control and indicator panel doors, thereby activating the limit switches connected to both doors and enabling current to flow through the circuit. Limit switches installed on both panel doors were for safety and to prevent accidents at work. A switch selector was employed to select the operating mode, either manual or automatic. The indicator light "ready" (yellow) illuminated when the selector switch was positioned to either operating mode. There were two inputs: a PB start for the manual operating mode and proximity sensors for the automatic mode

System outputs consisted of an induction motor and a gearbox connected to the conveyor and flattening units. The induction motor was manually operated when the PB start button was pressed; in automatic mode, the motor operated when common water hyacinths were placed on the conveyor. Proximity sensors were placed at both ends of the conveyor. If the sensors failed to detect work objects for ten seconds, the induction motor stopped operating, and

the machine returned to a standby position. The green indicator light, "ON" lit as a signal that the induction motor operated. In the manual mode, the PB stop was exploited to disable the induction motor.

A buzzer functioned as a system emergency indicator. The emergency switch was pressed during an emergency or upon detection of a system failure. When the switch was pressed, all processes stopped, and the push-button start was not functioning. A system evaluation should be made before the next system operation.

System power and control circuits are shown in Fig. 5. Processing inputs and outputs used PLC CP1H-X40DR-A. PLC inputs included PB start, PB stop, selector switch, limit switch, and proximity sensor. Fig. 6 shows the control and power system panel. PLC input addresses are suggested in Table 1. PLC outputs were light indicators, buzzers, and relays. PLC output addresses are demonstrated in Table 2.

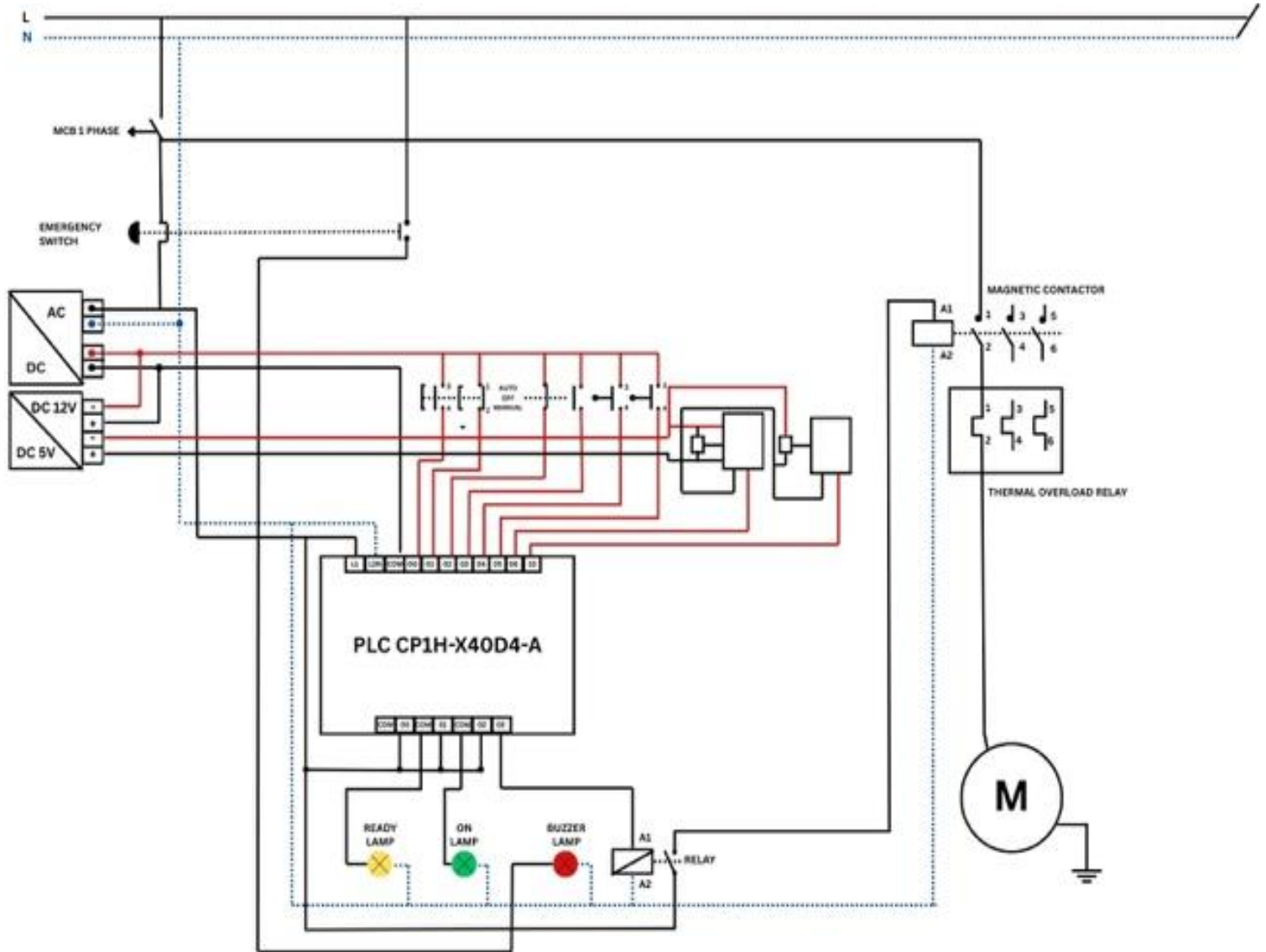


Fig. 5. System power circuit and control circuit

SCADA was leveraged in this research as an interface, monitoring, and control system. The implementation of SCADA systems in automatic systems offers numerous advantages, including improved monitoring and control, optimized resource usage, enhanced predictive maintenance, and real-time diagnostics. These benefits collectively contribute to increased system effectiveness and reliability, making SCADA a valuable tool in various industrial and utility applications [44], [45], [46]. The SCADA communication port used in this research was RS-232. The port was suitable for the PLC type utilized. First, ladder diagram programming on the PLC should be performed. PLC programming in this research was performed using CX-

Programmer, and SCADA design was implemented using CX-Designer.

Fig. 7 exhibits the SCADA design for the standard water hyacinth flattening machine. The SCADA display included a control panel, an indicator selector, and a conveyor display. The control panel was used to switch the system ON/OFF, operate it manually and automatically, and activate limit switches. The indicator selector was designed to visualize system work indicators and indicate system work hours. The conveyor displays encompassed the proximity, conveyor, flattening-area roller (section 1), and operator area (section 2).



Fig. 6. Power and control system panel

Table 1. PLC input addresses

Address	Input
0.00	PB start
0.01	PB stop
0.02	Manual mode of the selector switch
0.03	Auto mode of the selector switch
0.04	Limit switch 1
0.05	Limit switch 2
0.06	Proximity sensor 1
0.07	Manual mode of SCADA
0.08	Auto mode of SCADA
0.10	Proximity sensor 2
1.00	Start button via SCADA
1.01	Stop button via SCADA
T0000	Timer

Table 2. PLC output addresses

Address	Output
100.00	Yellow lamp indicator
100.01	Green lamp indicator
100.02	Induction motor
101.00	Manual indicator from SCADA
101.01	Auto indicator from SCADA
101.02	Auto indicator from the machine
101.03	Auto indicator from the machine
101.04	1st proximity sensor indicator
101.05	2nd proximity sensor indicator

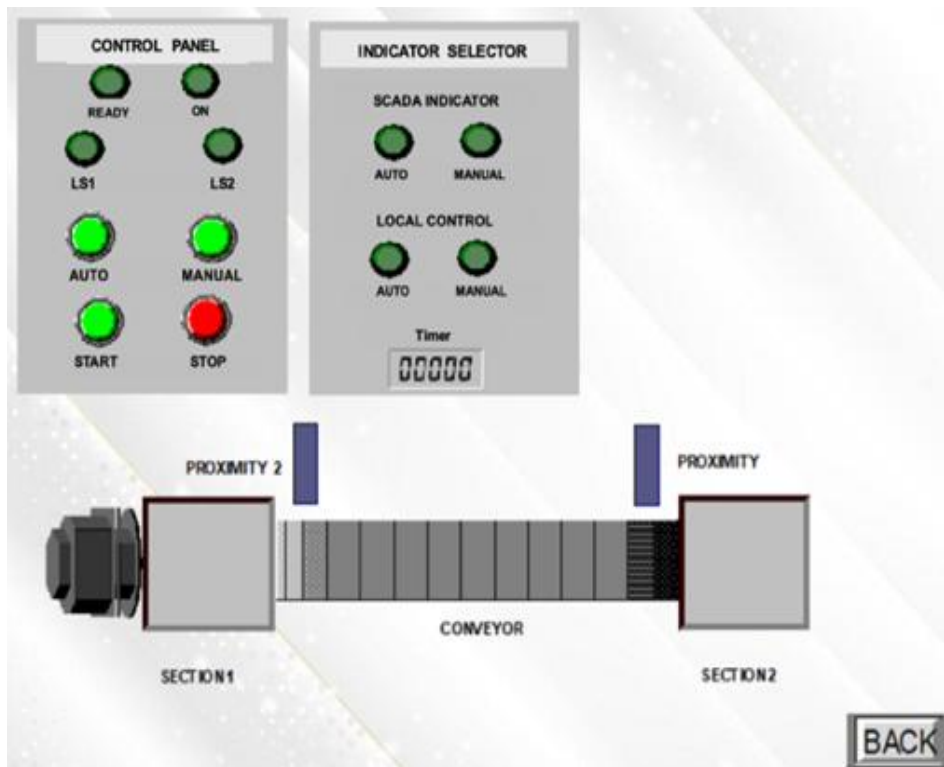


Fig. 7. SCADA design for the system

2.3 Solar power plant designing

A solar power plant supplying the standard water hyacinth flattening machine was designed to operate optimally. The block diagram of the power supply is shown in Fig. 8. Electricity consumption was calculated to determine the requirements of the installed components, thereby ensuring the system operates normally. Based on the power recapitulations in Table 3 and the system work descriptions, the load under peak conditions was 580.8 W. That is, the system's power supply requirements can be determined by calculating energy demand, battery capacity, solar panel capacity, inverter capacity, cable length, and system safety.

The solar power plant system, which was developed through planning, estimating, and designing, serves as the power supply for

the automatic common water hyacinth flattening machine and includes a 500 Wp solar panel, a 12 Ah battery, a 2000 W inverter, a 32 A MCB DC solar panel, a 48.3 A MCB DC battery, and a 4 A MCB AC. When using a 500 Wp solar panel, charging a 120 Ah battery required 5 hours under hot conditions. A 120 Ah battery, as the primary power source, was expected to adequately supply power to the automatic standard water hyacinth flattening machine.

Table 3. Recapitulation of power consumption in the power system

Component	Voltage (V)	Current (A)	Power (W)
Induction motor	220	2.6	572
2 Indicator lamp	220	0.04	8.8
Total		2.64	580.8

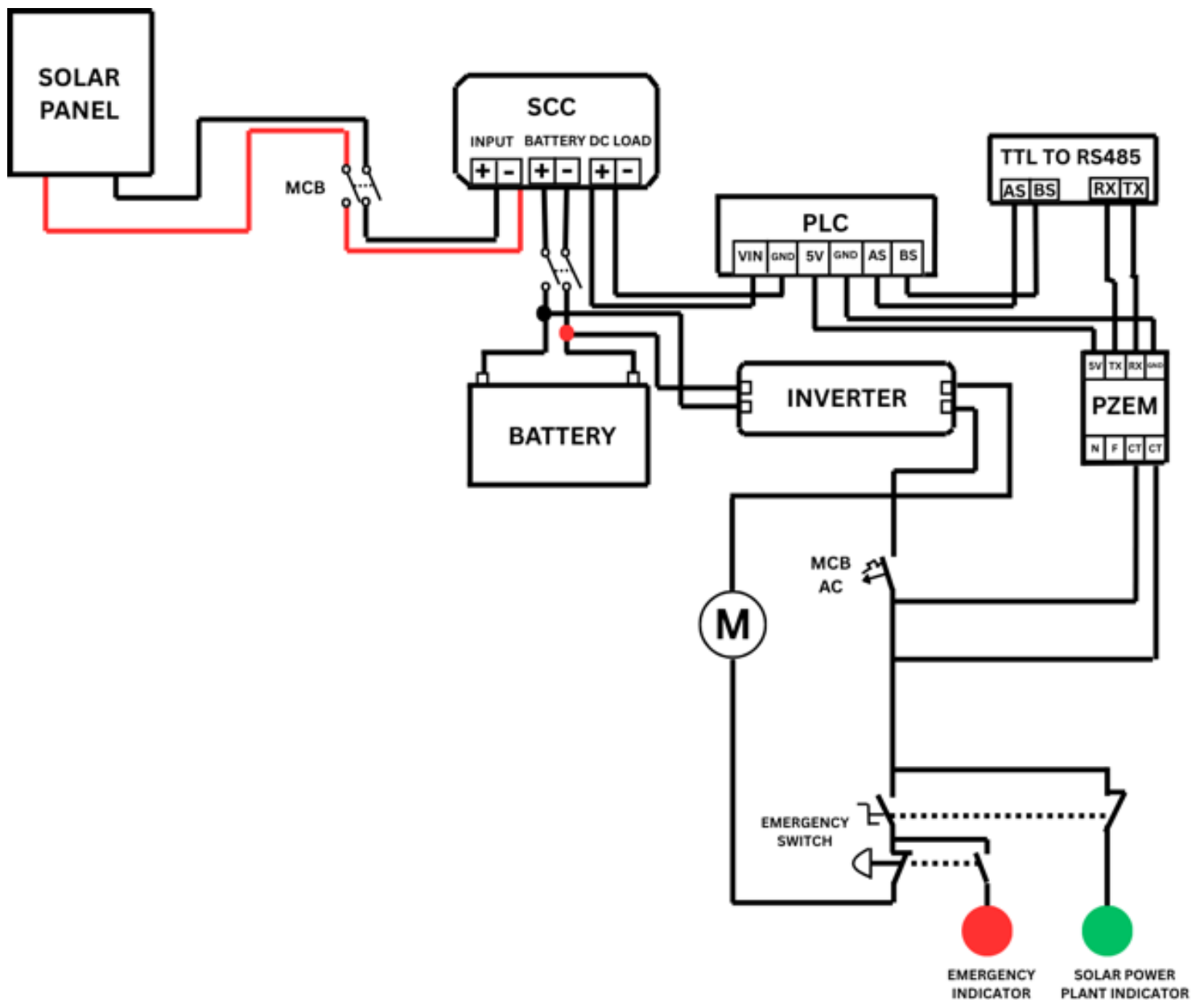


Fig. 8. Solar power plant block diagram

3 Results and discussion

Fig. 9 presents the research results for a standard water hyacinth flattening machine. The machine was tested to analyze its performance and production capacity. Testing was conducted on both manual and automatic systems. Testing was also performed on the off-grid solar power plant to assess its performance.

Machine performance testing was undertaken to collect data on voltage, current, output power, power factor, and engine frequency. The testing results are shown in Table 4. The average current, power factor, and output power were 1.93 A, 0.55, and 249 W, respectively. The use of output power indicated that the machine was operating optimally and thus could operate at a lower power level than its maximum capacity. Output power rose by 9.8% as the current rose. The power factor was low, averaging 0.55.

Table 5 presents a comparison of a conventional tool and a standard water hyacinth flattening machine. Testing was conducted to determine the number of common water hyacinths that could be flattened within a specified time at a constant speed using a single-phase motor. Three time points, 5, 10, and 15 minutes, were used during testing. Five sheets of common water hyacinth were placed on the conveyor at the same tempo. This can be observed in Table 5; using an automatic water hyacinth flattener machine can produce more production compared to conventional machines. On average, across 5-, 10-, and 15-minute machine experiments, the automatic water hyacinth flattening machine produced water hyacinth 58.35% more than conventional machines.



Fig. 9. Automatic flattening machine

Table 4. System output

Output	Period		
	5 min	10 min	15 min
Production capacity (gr)	340	627	834
Current (A)	1.90	1.94	1.95
Power (W)	235	256	258
Power factor	0.53	0.56	0.57

Table 5. Power capacity comparison

Period (min)	Conventional device (gr)	Automatic flattening machine (gr)
5	182	340
10	450	627
15	560	834

Fig. 10 presents a comparison of production capacity. Data attested to a linear increase in the number of common water hyacinths flattened with an increase in the operating time. As also implied by the data, the machine could be operated consistently and had production capacity that adequately met demand for typical water hyacinth handicrafts.



Fig. 10. Automatic flattening machine testing for flattening 5 common water hyacinths

Fig. 11 shows common water hyacinths before and after flattening with the automatic flattening machine. The pre-flattening standard water hyacinth stem was 0.9 mm, whereas the post-flattening stem was 0.2 mm, corresponding to the flattening roller setting. Five standard water hyacinth stems were flattened in a single cycle, producing flattened stems of the same size. The five flattened stems, which were flattened in a single cycle, suggested optimal flattening.

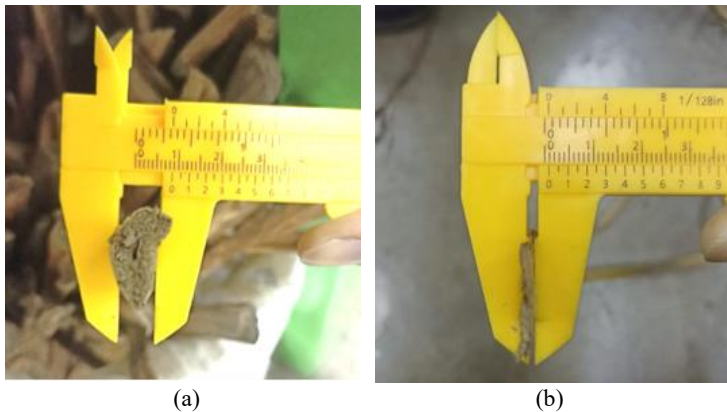


Fig. 11. (a) Common water hyacinths before; and (b) after being flattened

The flattening machine was equipped with a solar power plant as an alternative energy source. Based on the machine's power requirements, the solar power plant specifications specified a solar panel capacity of 500 Wp and a 12 V, 20 Ah battery. Fig. 15 shows the battery charging voltage and current measurements on the first and second days. Fig. 13 shows the battery charging voltage and current measurements on the third and fourth days. The tests were

conducted to evaluate the system's power supply performance. Battery charging began at 8 A.M. The battery was empty, and the charging voltage on the Solar Charger Controller (SCC) was set to 15 V. Testing on days 2 and 3 was conducted until noon due to rain and the PV system's inability to supply the battery. The average battery voltage was 14.43 V, and the average current was 2.88 A.

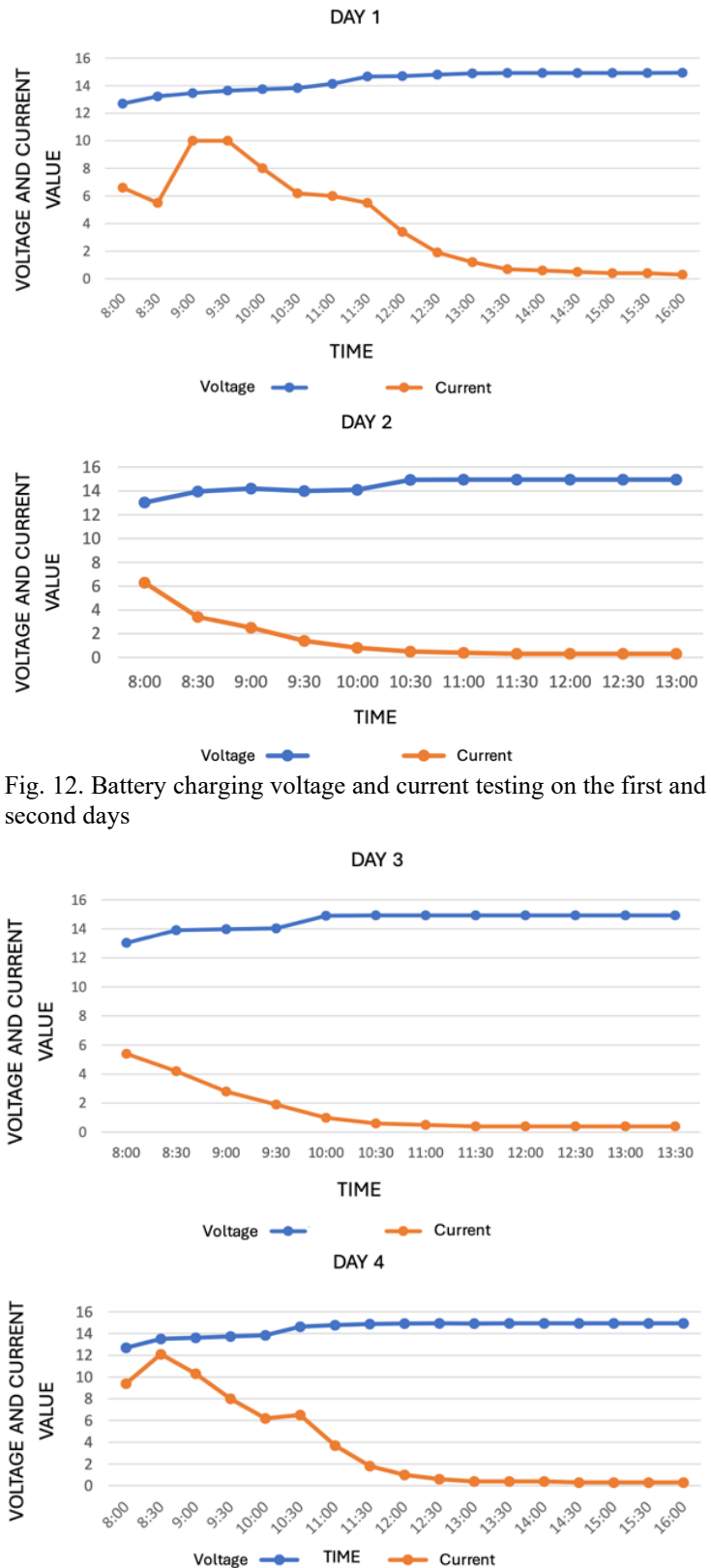


Fig. 12. Battery charging voltage and current testing on the first and second days

Fig. 13. Battery charging voltage and current testing on the third and fourth days

Table 6 demonstrates a solar power plant test with an automatic flattening machine load, where VB is the battery voltage, IC is the charging current, VC is the charging voltage, IL is the load current, VL is the load voltage, and PF is the power factor. Testing was performed on June 28th, 2024, starting at 1 P.M. The battery voltage was 13.79 V, the charging current was 10.1 A, and the load

current was 2.08 A. After 90 minutes of testing, the battery voltage dropped to 10.20 V, the charging current was 1 A, and the load current was 1.6 A. It stopped the flattening machine from operating. Testing demonstrated that the solar power plant could supply power optimally for 1.5 hours at an average power demand of 249 W. The analysis indicated that the solar power plant could support machine operations for a limited time. Solar power plant limits were due to the limited capacity of batteries and solar panels. The solar power plant was effective for short-term use, as it could supply power to the flattening machine for 1.5 hours, but was ineffective for long-term operation.

Table 6. Solar power plant test with an automatic flattening machine load

Time	V _B	I _C	V _C	I _L	V _L	PF
13.00	13.79	10.1	15	2.08	225	0.41
13.30	12.50	4.5	15	2.02	225	0.44
14.00	12.20	5.1	15	1.90	225	0.42
14.30	10.20	1.0	15	1.60	193	0.50

Energy efficiency was measured by comparing conventional power consumption with that of the solar power plant. Based on the

test results, the average traditional electrical energy consumption was 249 W, whereas the solar power plant supplied 232 Wh. Accordingly, the flattening machine could operate with relatively low energy consumption. Solar power plants are an alternative energy source that does not burden conventional power systems and supports the utilization of renewable energy in areas with electricity constraints. Drawing on solar power plant energy could efficiently meet machine power needs for a limited period, yet it was unable to meet all machine needs over a long operating duration.

PLC and SCADA-based control systems for the flattening machine were designed to ensure automated operation and real-time monitoring. During testing, the PLC-based control system executed instructions according to the programmed sequence, e.g., activating and deactivating the motor at specified intervals and receiving inputs from proximity sensors. The input addresses of both limit switches and both proximity sensors were active, and the induction motor output was then operated. The ladder diagram of the manual flattening machine system, shown in Fig. 14, indicates that when input addresses were active, the light indicator and motor were in the ON position.

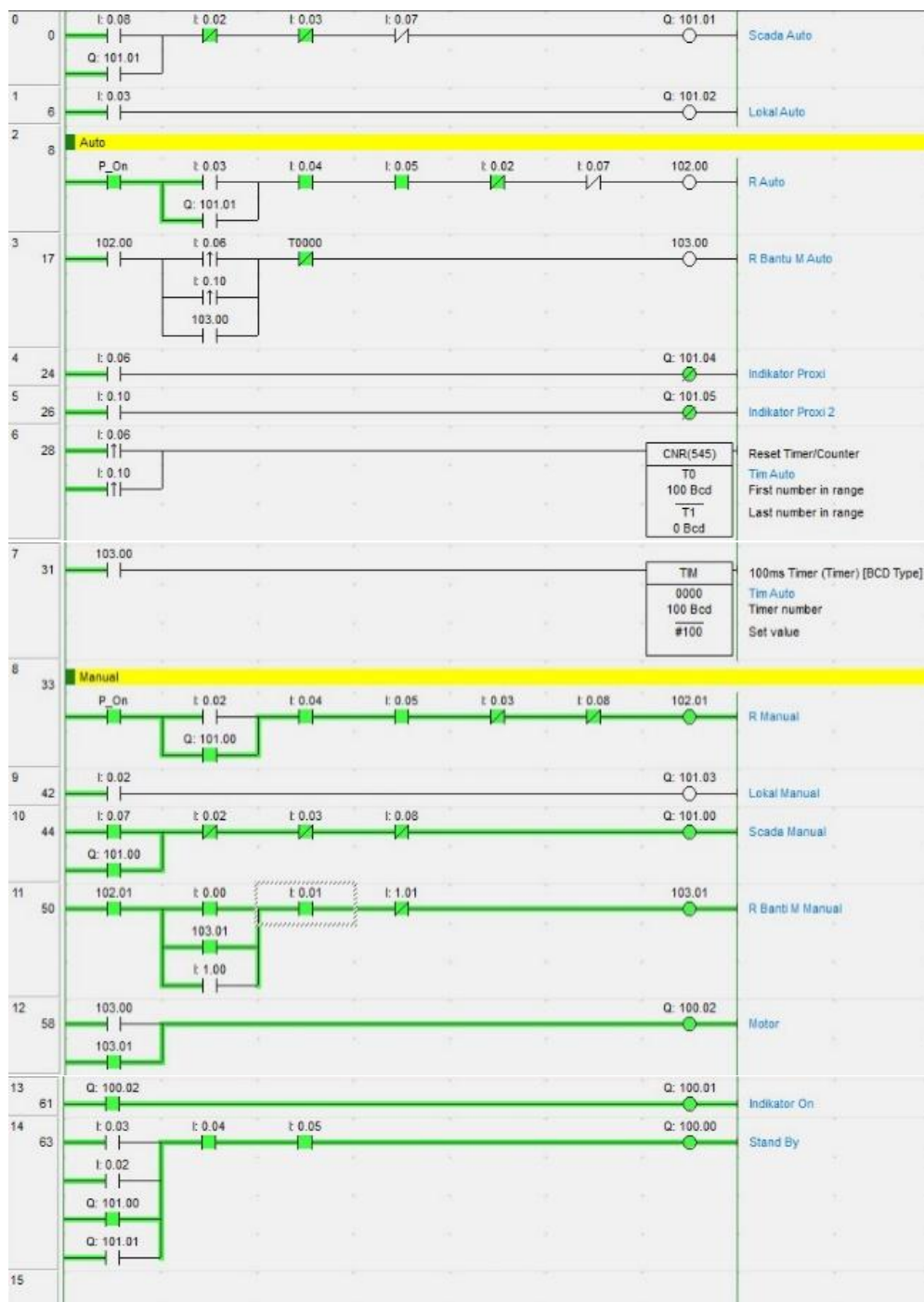


Fig. 14. The output address on the PLC is active

Fig. 15 presents the power consumption values of the flattening machine in manual and automatic modes. Output power was 210 W. The automatic mode was proven to be more power-efficient than the manual one. Power efficiency was 28.33%. This was because, in automatic mode, the machine operated only when its proximity sensors received signals. The machine continued to operate for ten seconds after work objects did not touch the sensors.



Fig. 15. Digital power meter measurement in: (a) automatic mode; and (b) manual mode

The SCADA system could display the machine's operational status. During monitoring, operators can readily assess machine conditions and quickly identify operational issues. No errors were found during testing, indicating the reliability of the control and monitoring systems. SCADA also had an automatic alarm capability, which was active in problematic or emergency conditions, such as when the solar power plant battery was low, or the machine exceeded its power limit.

4 Conclusion

This study demonstrates the design and implementation of an automatic common water hyacinth flattening machine powered by an off-grid solar power plant. The design increases production capacity to 834 grams in 15 minutes. The size of flattened common water hyacinths was 0.2 mm, as determined by the roller setting. The system operates with an average power consumption of 249 W, which can be reliably supplied by the solar power plant for up to 1.5 hours. The system was an effective alternative power source, but its capacity should be increased to achieve maximum operations without time limitation. PLC and SCADA-based automatic control systems run reliably, allowing easy monitoring and maintaining machine operation stability and safety. It is recommended that future research focus on the manufacturing and integrating the machine with the Internet of Things (IoT).

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