DESIGNING A SCADA-BASED MONITORING AND CONTROL SYSTEM FOR A SOLAR-POWERED LIVESTOCK FEED PRODUCTION MACHINE

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ABSTRACT
Livestock feed production in small- and medium-scale farming still relies heavily on manual control and limited energy monitoring, resulting in operational inefficiency, higher production costs, and difficulty in tracking real-time electricity consumption. This study aimed to design a Supervisory Control and Data Acquisition (SCADA)-based monitoring and control system for a livestock feed production machine integrated with a solar photovoltaic power system. The research employed a Research and Development approach, involving problem identification, literature review, descriptive field analysis, hardware and software design, PLC ladder diagram development, and Human Machine Interface dashboard design. The proposed system integrates key SCADA components, including PLC, HMI, sensors, power meter, communication modules, and photovoltaic energy support. The design results show that the system can monitor electrical parameters such as voltage, current, power, energy consumption, and frequency in real time. The HMI dashboard enables operators to access data through tables, graphs, historical records, control menus, and alarm threshold settings. The study concludes that integrating SCADA with solar-powered livestock feed production technology can improve monitoring accuracy, operational efficiency, system safety, and energy sustainability. This research contributes to the development of smart farming technology by offering a conceptual model for automated, renewable-energy-based production systems. Future studies should focus on prototype implementation, field testing, cost-benefit analysis, and performance evaluation under different livestock production conditions.
Keywords: Animal feed manufacturing, human-machine interface, photovoltaic energy, programmable logic controller, supervisory control and data acquisition

INTRODUCTION

Industrial automation has become increasingly important for improving efficiency, consistency, safety, and traceability in production systems. These requirements are also relevant to livestock enterprises because the quality and continuity of feed production directly influence animal growth, farm productivity, and operating cost. Animal feed manufacturing generally involves ingredient preparation and weighing, grinding, mixing, forming or pelleting, conveying, and discharge. Each stage requires stable machine operation and coordinated control. In many small- and medium-scale enterprises, however, equipment is still started and stopped manually, operating conditions are observed directly at the machine, and production records are not integrated. Such practices increase dependence on operator experience, make disturbances more difficult to diagnose, and limit the availability of information for evaluating production and energy efficiency.

The electrical demand of feed-processing equipment is dominated by motors used for grinders, mixers, conveyors, forming units, and auxiliary systems. Without continuous measurement, operators cannot readily determine whether a motor is overloaded, whether power consumption is increasing abnormally, or how much electrical energy is used for a production batch. Dependence on conventional grid electricity may also increase operating costs and expose enterprises to supply interruptions. Photovoltaic energy provides an alternative or complementary source for supplying control circuits, lighting, and production loads, particularly where solar resources are available. Nevertheless, adding photovoltaic modules alone does not ensure efficient operation. The source, storage system, inverter, distribution panel, and production loads must be monitored as an integrated energy system.

Supervisory Control and Data Acquisition (SCADA) technology provides a framework for collecting field data, executing supervisory commands, presenting process information, generating alarms, and storing historical records. A typical architecture combines field sensors and actuators, a Remote Terminal Unit or Programmable Logic Controller (PLC), industrial communication, a Human-Machine Interface (HMI), a database, and a supervisory server. Previous photovoltaic applications have demonstrated that SCADA can display electrical and environmental parameters, support alarm and logging functions, and enable remote supervision (Ahsan et al., 2022; He et al., 2025; Mohammed & Al-Naib, 2023). In automated feeding applications, HMI functions have supported plant monitoring, control, alarm management, and database storage, while solar-powered feeder systems have shown the practical value of combining renewable energy and automated feed delivery (Azis et al., 2017; Boonraksa & Boonraksa, 2025; Syahid et al., 2023).

Despite these developments, prior studies generally emphasize either photovoltaic monitoring, open-source IoT-SCADA platforms, or the automation of a feeding device. They do not present an integrated conceptual design that combines photovoltaic-side energy supervision with the complete control requirements of animal feed manufacturing equipment for small- and medium-scale livestock production. The proposed study addresses this gap by unifying the panel configuration, electrical measurement, PLC control logic, HMI navigation, alarm thresholds, historical data, and remote access within one implementation framework. The novelty lies in linking every monitoring feature to a specific operational decision: electrical measurements are used to identify overload and unstable supply conditions; trend and historical data support energy evaluation and maintenance; alarms support rapid intervention; and the process interface supports coordinated operation of the feed-production stages.

Accordingly, the objective of this study was to design a photovoltaic-powered SCADA concept for animal feed manufacturing equipment that is technically coherent, operator-oriented, and suitable for subsequent prototype development. The study specifically sought to define the operating scenario and design requirements, develop the hardware and communication architecture, formulate the PLC and HMI functions, describe the decision value of the dashboard features, and establish preliminary criteria for future validation.

METHOD

This study used a Research and Development approach at the conceptual-design stage. The work did not claim full prototype performance; instead, it produced an integrated engineering design and a validation plan that can guide construction and field testing. The development process combined descriptive inquiry with systems engineering. Literature on photovoltaic monitoring, SCADA architecture, PLC-HMI integration, and automated feeding was reviewed to identify appropriate functions and communication practices. Direct interviews with representatives of livestock groups and prospective operators were used to understand operational constraints and the information required during feed production.

The research subjects were the intended users and operating environment of small- and medium-scale animal feed production. Because the source manuscript did not report a numerical sample, the interviews were treated as requirements-elicitation inputs rather than as a statistical survey. The instruments consisted of a semi-structured interview guide, a process-observation checklist, a technical specification worksheet, and a conceptual verification checklist. The interview guide focused on current operating procedures, difficulties in monitoring machine status and energy use, disturbance handling, preferred display formats, and the need for remote supervision. The technical worksheet mapped each requirement to field devices, PLC inputs and outputs, communication links, HMI objects, database tags, and alarm conditions.

Data collection proceeded through four activities. First, the existing feed-production sequence and representative loads were described. Second, user needs were translated into measurable or observable system requirements. Third, component and communication alternatives were examined using published studies and standard industrial practices. Fourth, the resulting design was checked for functional completeness, data-flow continuity, safety logic, and alignment with the identified needs. Qualitative content analysis was used to group the interview information into operational, monitoring, control, data-management, and accessibility requirements. Functional decomposition was then applied to assign each requirement to the PV subsystem, distribution panel, PLC, field instruments, HMI, database, or remote interface.

The intended operating scenario begins with the preparation and weighing of raw materials, followed by grinding, mixing, feed forming, conveying, and discharge. The principal loads are motor-driven processing units and auxiliary lighting. Because final motor ratings, production capacity, and PV sizing were not available in the source document, the present work defines the architecture and signal requirements without claiming a fixed installed capacity. Final component selection must therefore be completed during detailed engineering after the rated current, starting current, duty cycle, daily operating hours, and expected production volume have been measured.

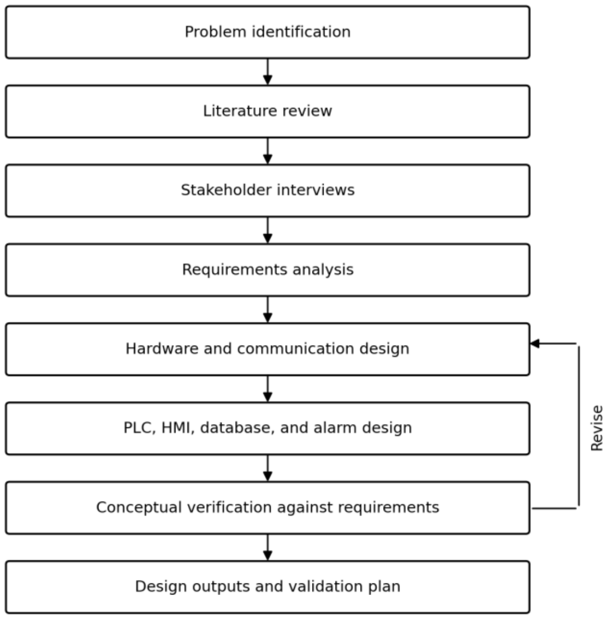

Figure 1. Research and development stages for the conceptual SCADA design.

As illustrated in Figure 1, the design process moved from problem identification and evidence review to stakeholder interviews, requirements analysis, hardware and software design, conceptual verification, and preparation of design outputs. Verification was iterative: any missing signal, control action, alarm, or decision-support function was returned to the corresponding design stage for revision. The principal outputs were the system architecture, panel component plan, PLC ladder concept, HMI screen structure, database and alarm functions, and preliminary validation criteria.

Table 1. Design requirements and corresponding SCADA functions

Identified operational need	Design requirement	SCADA response
Manual observation of machine conditions	Centralized status information	HMI status indicators for motors, process stages, and interlocks
No continuous record of electricity use	Real-time and historical energy supervision	Power meter tags for voltage, current, power, energy, and frequency; database trends and reports
Delayed recognition of abnormal operation	Immediate warning and protective action	Adjustable alarms, event logging, and PLC trip/interlock logic
Difficulty diagnosing disturbances	Traceable operating history	Time-stamped alarms, parameter trends, and machine-state records

Identified operational need	Design requirement	SCADA response
Need for simple operation	Clear and consistent interface	Home screen, navigation buttons, numerical displays, tables, trends, and role-based commands
Need for off-site supervision	Controlled remote accessibility	Cloud or secure gateway access with user authentication and read/write permissions

RESULTS AND DISCUSSION

Design Context and Operating Scenario

The conceptual result is a coordinated production and energy-management system rather than a stand-alone monitoring screen. Figure 2 summarizes the application context: photovoltaic energy supplies the electrical system, SCADA supervises the process, raw ingredients enter the production machine, and finished feed is discharged. This context is important because the control system must simultaneously observe the energy source, the electrical distribution, and the production sequence. A disturbance in one domain can affect the other. Low battery voltage or unstable inverter output, for example, can interrupt a motor-driven stage, while an overloaded grinder can increase demand and reduce the available energy margin.

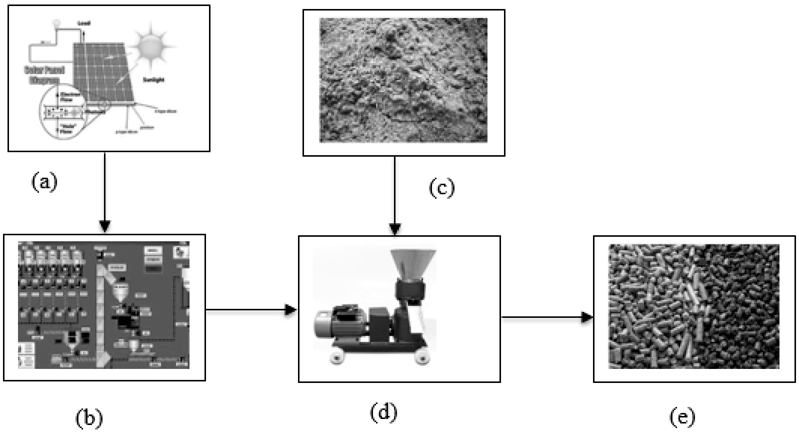

Figure 2. Application context of photovoltaic energy, SCADA, raw materials, feed-processing equipment, and product output.

The operating concept is intended for batch production. Before a batch begins, the operator verifies that the energy source is available, emergency stops are reset, protective devices are healthy, and the required machines are ready. The sequence then progresses through ingredient preparation, grinding, mixing, forming, conveying, and discharge. Each stage is associated with permissive conditions and interlocks. A downstream unit should be available before the upstream conveyor starts, and a motor trip should stop dependent equipment in a controlled order. This sequence reduces material accumulation and provides a basis for safer restart after a disturbance.

SCADA Components and Communication Structure

The SCADA structure comprises the HMI, supervisory or master terminal function, PLC/RTU, field devices, and communication network. Figure 3 presents the general relationship among these elements. The HMI is the operator interface for viewing measurements, commands, alarms, and trends. The supervisory server manages tag data, user access, historical storage, and communication with the PLC. The PLC executes deterministic control logic and receives signals from sensors, power meters, push buttons, and protection devices. Field devices include current transformers, voltage and frequency measurement, level or status sensors, relays, contactors, variable-frequency drives where applicable, and motor-protection contacts.

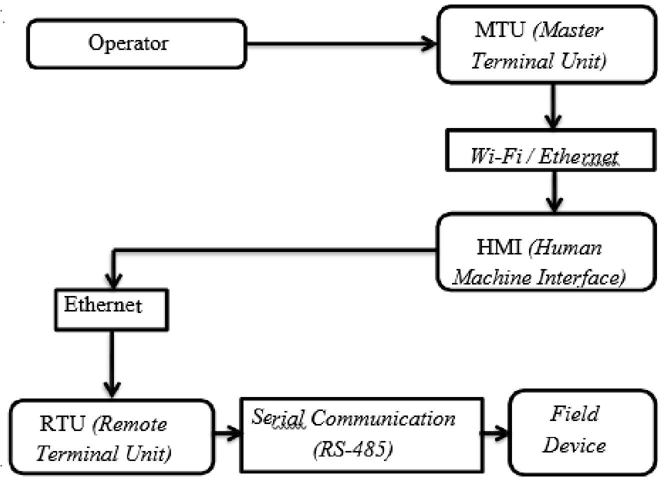

Figure 3. General structure of the supervisory control and data acquisition system.

The communication design uses Modbus RTU over RS-485 for power meters or compatible field instruments and Ethernet for PLC-to-SCADA communication. Wi-Fi may be used between the local network and an operator device when reliable coverage and appropriate security controls are available. The use of standardized protocols simplifies tag mapping and allows replacement of compatible instruments without redesigning the complete system. The cloud function is positioned as a controlled remote gateway, not as the primary control path. Essential control and protection must remain local so that loss of internet connectivity does not stop the production process or disable safety functions.

Integrated Energy and Data Architecture

Figure 4 is the added system block diagram requested during peer review. It clarifies the complete data and energy flow. The energy path extends from the PV array through the charge controller, battery, inverter, and distribution panel to the machine loads. The data path begins at sensors and the power meter, passes to the PLC, and continues to the SCADA server, HMI, historical database, cloud gateway, and remote user. Control commands return from the PLC through relays, contactors, or variable-frequency drives to the loads. This separation between energy flow and information flow makes the design easier to verify and prevents the common ambiguity in which the location of measurement, control authority, and remote access is not clearly defined.

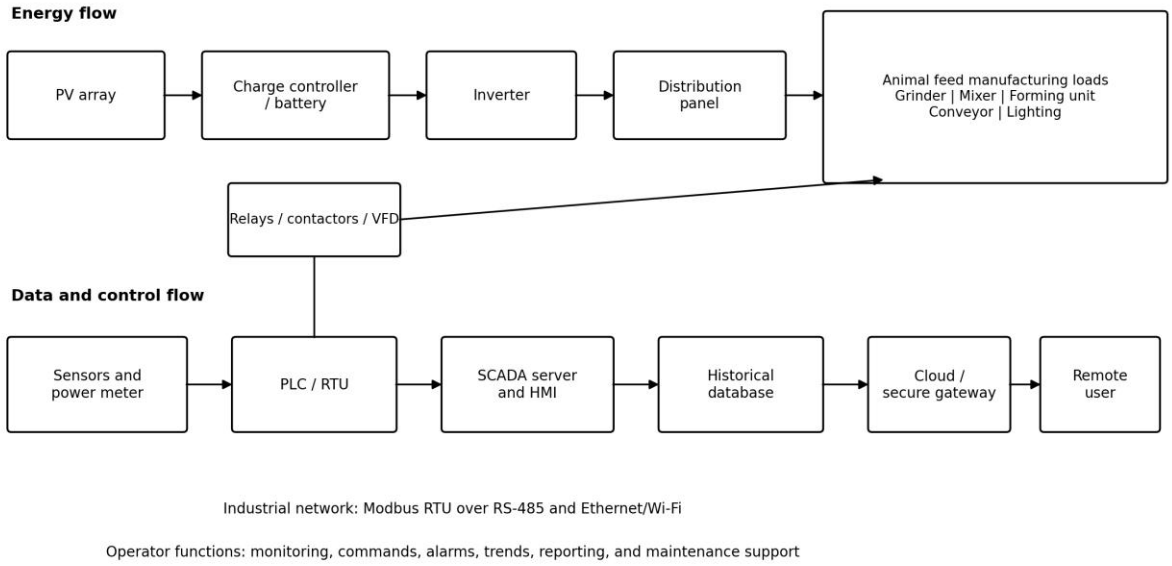

Figure 4. Integrated energy, data, control, storage, and remote-access architecture.

The architecture also defines the direction of operational responsibility. Sensors and meters provide raw measurements; the PLC validates signals and applies interlocks; the SCADA server converts tags into operator information; the database preserves evidence for analysis; and the remote interface supports supervision under assigned permissions. A remote user may acknowledge an alarm or issue an authorized command, but the PLC remains responsible for ensuring that permissive and safety conditions are satisfied. This arrangement is consistent with the requirement for local autonomy and reduces the risk that network delay or cloud unavailability will compromise essential operations.

Panel Component and Protection Design

The panel design integrates power distribution, protection, measurement, control, and interface equipment. The principal components are a molded-case circuit breaker, miniature circuit breakers, fuses, busbars, current transformers, a 24 V DC power supply, power meter, PLC, communication equipment, relays or contactors, and HMI. Figure 5 shows the proposed component network. The incoming protection device isolates the panel, branch protection separates the processing loads, and the 24 V DC supply provides stable power for PLC inputs, sensors, and communication devices. Current transformers feed the power meter where direct measurement is not appropriate, while auxiliary contacts return breaker and contactor status to the PLC.

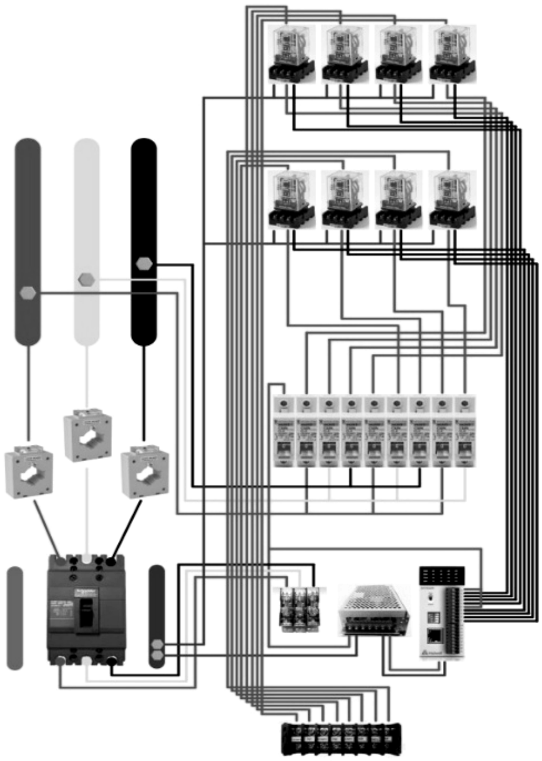

Figure 5. Proposed SCADA panel component network and electrical interconnections.

For detailed engineering, the panel components must be selected according to measured load characteristics. Motor starting current, cable ampacity, short-circuit capacity, environmental temperature, enclosure protection, earthing, and separation of power and signal wiring must be considered. The conceptual drawing therefore functions as a topology, not as a final construction drawing. Before installation, it should be converted into single-line diagrams, control schematics, terminal plans, cable schedules, and a bill of materials. This clarification limits overinterpretation of the conceptual result and establishes the work required before fabrication.

PLC Ladder Logic and Control Functions

The PLC ladder design is the principal logic layer of the system. It receives start, stop, emergency, protection, and process signals; evaluates permissive conditions; commands actuators; and exchanges measurement data with the HMI. Figure 6 illustrates the use of ladder instructions for communication and data movement. The logic should be organized into functional blocks for system initialization, manual/automatic mode selection, machine sequencing, energy permissives, alarm generation, communication handling, and safe shutdown. Separating these functions improves readability and simplifies testing.

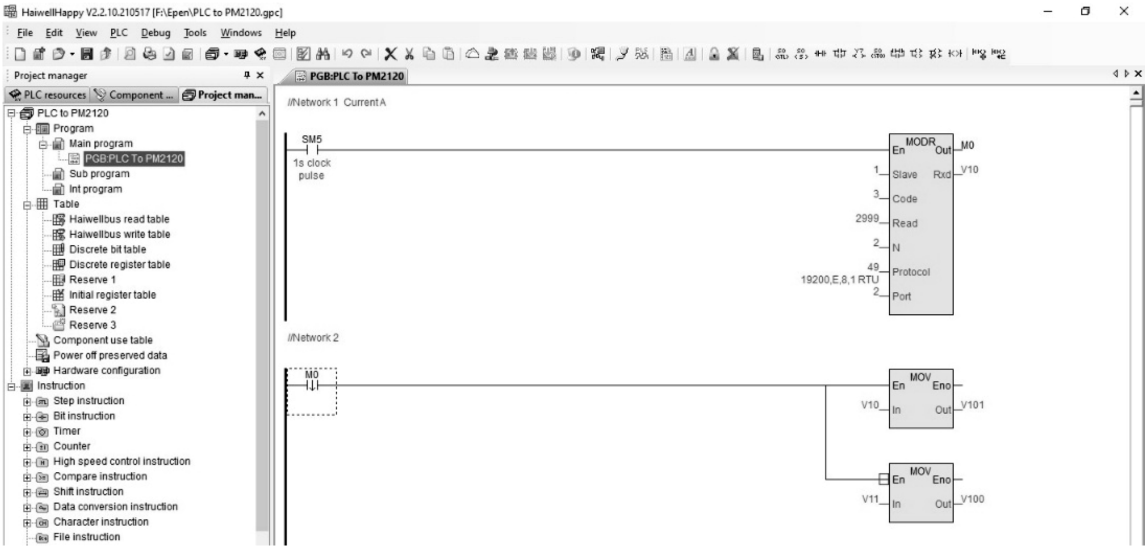

Figure 6. PLC ladder logic for communication and data-transfer instructions.

The proposed sequence uses interlocks to prevent operation when an unsafe or incomplete condition exists. A machine start request is accepted only when the emergency circuit is healthy, the relevant protective device is reset, the energy source is within the allowed range, and the dependent equipment is ready. When an overload or abnormal electrical condition is detected, the PLC records the event, stops the affected load, and prevents automatic restart until the cause has been acknowledged and cleared. Manual mode is retained for maintenance and commissioning, but it should not bypass emergency stops or motor protection. This design gives the operator flexibility while preserving essential safeguards.

HMI Navigation and Process Control

The HMI is designed as a structured navigation system rather than a collection of unrelated screens. The initial screen in Figure 7 provides access to process control, electrical monitoring, alarm management, historical data, and system settings. The home screen should display a concise summary of energy availability, production status, active alarms, and communication health. Detailed screens are opened only when the operator needs to investigate or control a particular subsystem. This hierarchy reduces visual overload and supports faster interpretation by users with different levels of technical experience.

Figure 7. Initial HMI screen and navigation concept.

The control screen illustrated in Figure 8 uses status lamps and command buttons for the lighting circuits. The same interaction principle can be applied to feed-processing motors: a neutral state indicates that the device is available but stopped, a running state confirms energized operation, and a fault state identifies a trip or unavailable condition. Commands should use consistent symbols and confirmation behavior. Where a command can interrupt production or create a hazardous transition, the HMI should request confirmation and display the reason when the PLC rejects the command.

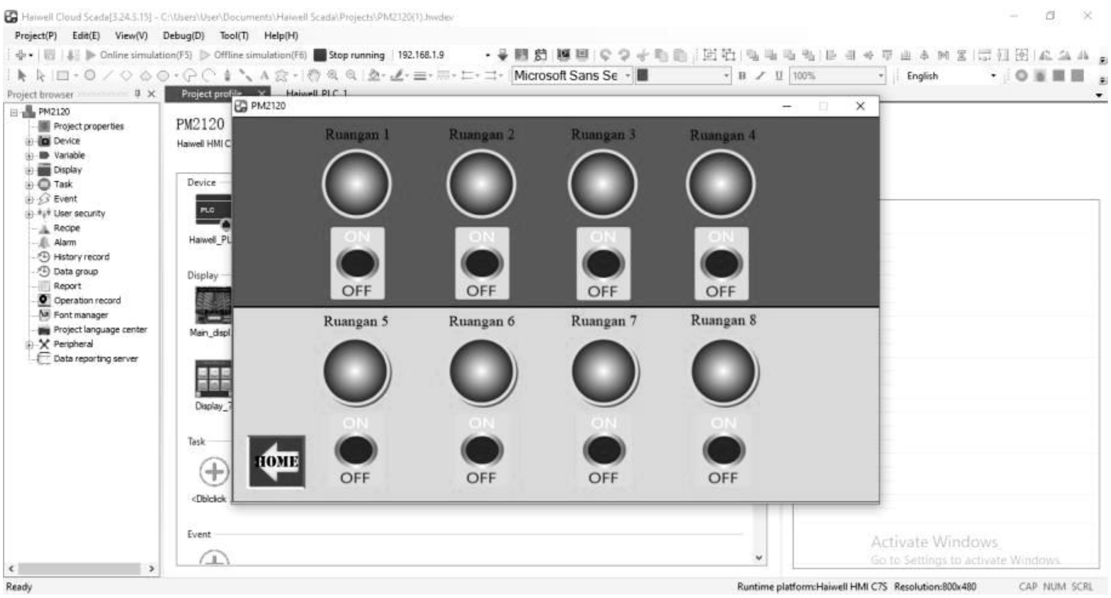

Figure 8. HMI dashboard for lighting control and equipment-status visualization.

Electrical Monitoring and Operational Decisions

The electrical dashboard is designed to convert measurements into decisions. Figure 9 presents real-time current values. Current is a direct indicator of motor loading and can reveal overload, blockage, bearing deterioration, or an unexpected process condition. A current value above the warning threshold prompts the operator to inspect the material flow and machine condition; a value above the trip threshold initiates PLC protection. Conversely, an abnormally low current while a motor is commanded to run may indicate a broken coupling, empty process stage, failed contactor, or incorrect feedback signal.

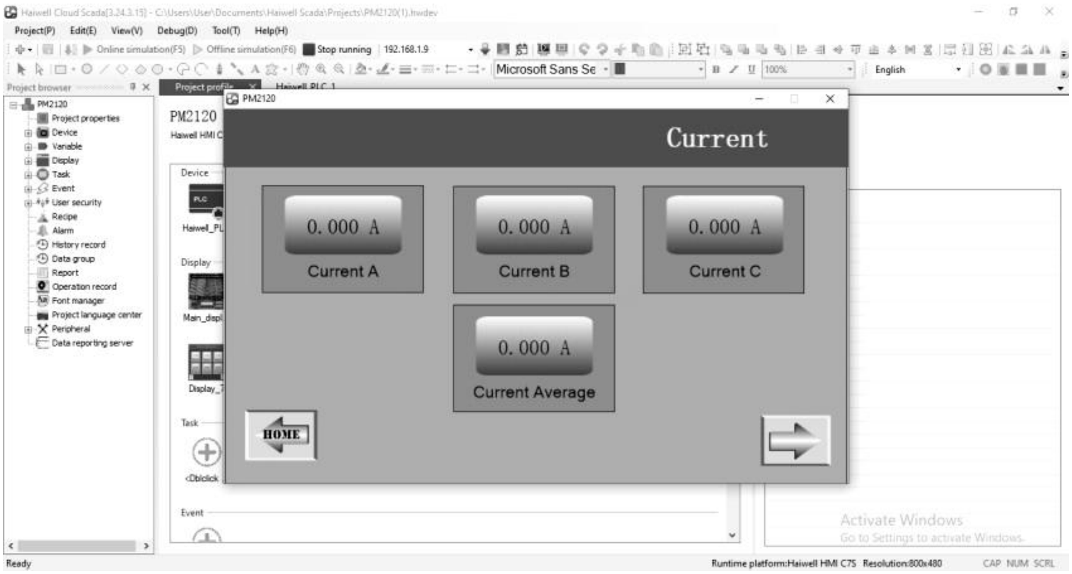

Figure 9. Electrical-current monitoring dashboard for real-time load supervision.

The trend display in Figure 10 combines voltage, current, and frequency. The operator can use voltage and frequency trends to distinguish a machine problem from a supply problem. Stable voltage and frequency with rising current point toward a load-side disturbance, whereas simultaneous changes in supply parameters may indicate inverter limitation, battery depletion, or an external electrical disturbance. Trend duration should be selectable so that operators can view short transients during starting, compare complete production batches, or evaluate daily energy patterns. The active-power and energy tags should be included in the same data model even when they are shown on separate screens.

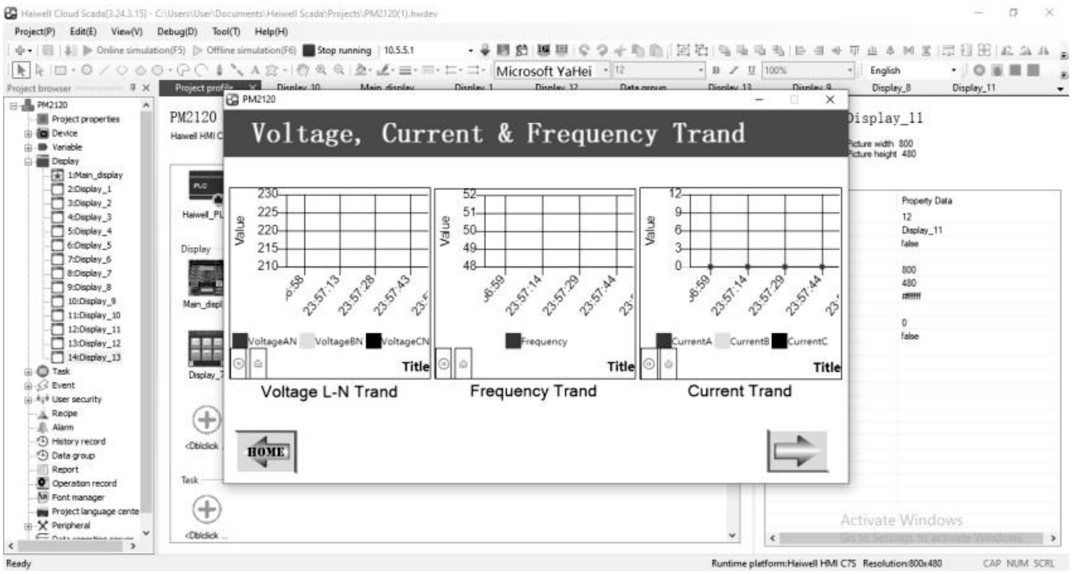

Figure 10. Trend dashboard for voltage, current, and frequency analysis.

Historical tables, shown in Figure 11, provide traceability. Each record should contain a timestamp, parameter value, unit, machine or circuit identifier, operating mode, and alarm state when relevant. Historical data support three practical decisions. First, supervisors can compare energy consumption among batches and identify increasing consumption for the same production task. Second, maintenance personnel can examine parameter behavior before a trip and prioritize inspection. Third, managers can estimate the contribution of photovoltaic energy and determine whether battery, inverter, or PV capacity should be adjusted. These functions extend the system from immediate monitoring to evidence-based operational management.

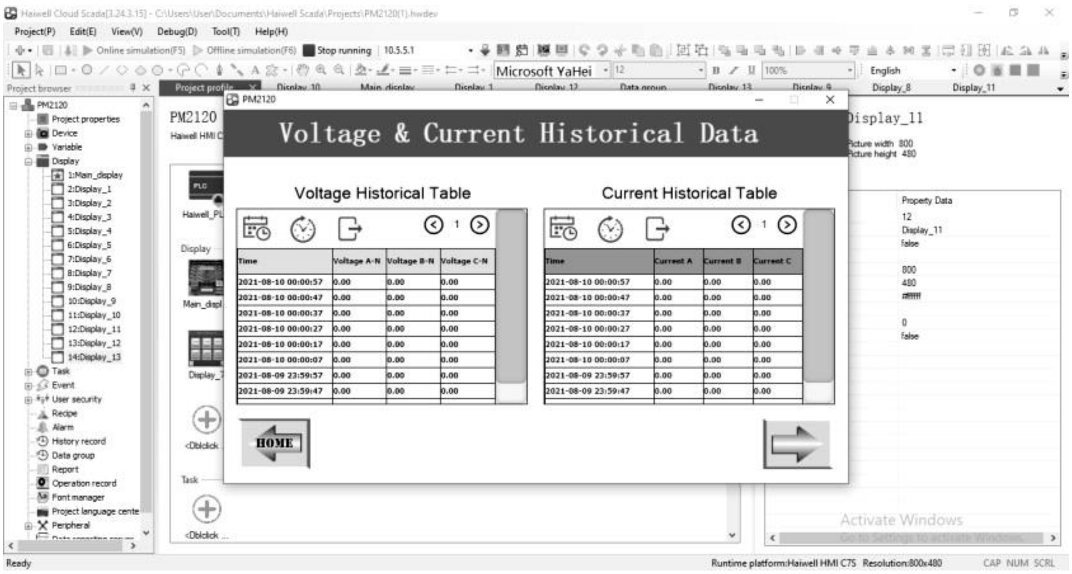

Figure 11. Historical voltage and current data tables for traceability and analysis.

The alarm-setting screen in Figure 12 allows authorized personnel to define warning and trip thresholds for voltage, current, frequency, and other process variables. The design should separate advisory alarms from protective trips. An advisory alarm informs the operator that a condition is approaching an unacceptable range, whereas a trip requires automatic action to protect equipment or maintain safe operation. Each alarm must include a clear message, timestamp, measured value, threshold, acknowledgement state, and return-to-normal record. Alarm settings should be password-protected and changes should be logged because inappropriate values can either create nuisance alarms or leave equipment insufficiently protected.

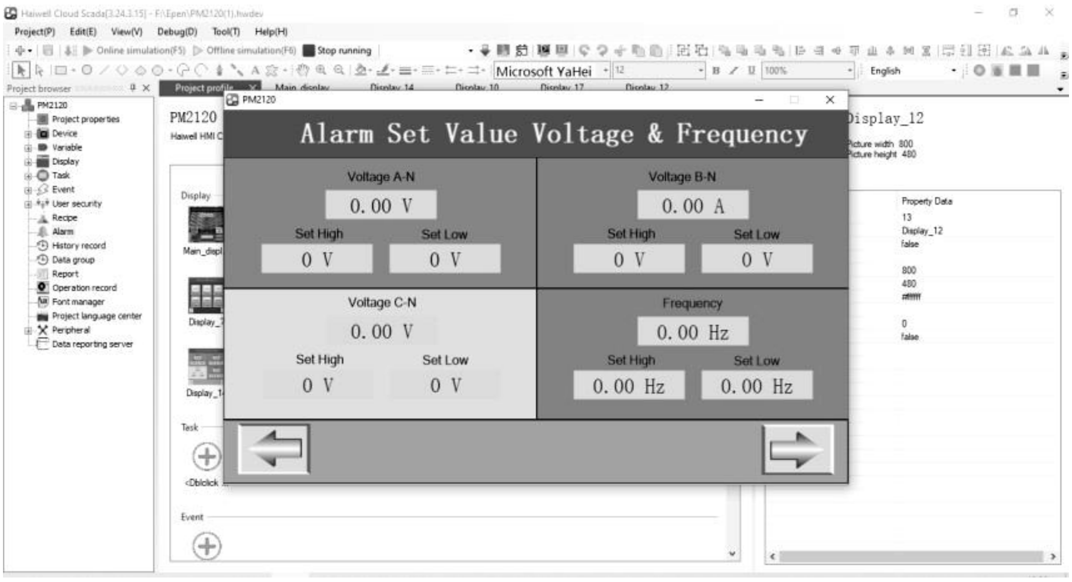

Figure 12. HMI screen for configurable electrical alarm thresholds.

Preliminary Validation Criteria and Implementation Limits

Because the present output is a conceptual design, performance statements must be expressed as validation targets rather than as experimentally proven results. Table 2 defines preliminary acceptance criteria for prototype testing. The targets are intentionally practical for a small industrial control system and should be refined after the selected meter, PLC scan time, network configuration, HMI platform, and load characteristics are known. Prototype validation should include calibrated reference measurements, simulated abnormal conditions, repeated command tests, communication interruption, database continuity, and operator usability assessment.

Table 2. Preliminary performance indicators for prototype validation

Indicator	Preliminary design target	Proposed verification
Voltage, current, and power measurement error	Not more than 2% against a calibrated reference within the operating range	Compare SCADA values with a calibrated meter at low, medium, and high loads
Local dashboard refresh interval	Not more than 2 s during normal operation	Record tag timestamps and screen updates under representative network traffic
Local supervisory command response	Not more than 1 s from accepted HMI command to PLC output change	Repeat start/stop and mode commands and measure end-to-end delay
Alarm indication time	Not more than 2 s after the PLC confirms a threshold violation	Inject simulated abnormal values and measure alarm appearance and logging
Historical-data completeness	At least 99% of expected records during a test period	Compare configured sampling count with database records and timestamps
Local communication availability	At least 99% during controlled endurance testing	Log connection state, packet errors, and recovery after cable/network interruption
Safe loss-of-network behavior	Local PLC control and protection remain functional	Disconnect cloud/internet access and verify local operation, alarms, and data buffering

Remote accessibility introduces requirements that are different from local panel control. The cloud or gateway connection should use individual accounts, strong authentication, encrypted communication, and role-based permissions. Operators may receive read access and alarm acknowledgement, while engineering changes, alarm-threshold modification, and manual output commands should be restricted to authorized personnel. The local control network should be separated from general office or public wireless networks, and the PLC should not be directly exposed to the internet. Configuration backups, user-action logs, time synchronization, and periodic password review are necessary so that operational events remain traceable. Maintainability is equally important for small enterprises. Tag names, wire numbers, terminal labels, alarm messages, and screen navigation should use consistent terminology, while the panel should include spare terminals and documented communication settings. A maintenance screen can display device communication status, PLC health, storage availability, sensor plausibility, and the date of the most recent inspection. These provisions do not change the basic production sequence, but they improve the likelihood that the system can be operated, diagnosed, and restored without prolonged dependence on the original developer.

Several limitations remain. The design does not provide final motor ratings, PV capacity, battery autonomy, inverter sizing, sensor ranges, cybersecurity configuration, or production throughput because these data were not available in the source manuscript. It also does not demonstrate measured efficiency improvement or cost savings. These outcomes should be evaluated only after prototype fabrication and field trials. Future work should therefore complete detailed electrical design, conduct hazard and failure-mode analysis, implement authenticated user roles and network segmentation, test the system under representative feed materials, and quantify energy consumption per unit of product.

CONCLUSION

This study produced a template-compliant conceptual design for a photovoltaic-powered SCADA system for animal feed manufacturing. The revised design defines the operating scenario, integrates the PV source and production loads, clarifies the complete data and control flow, and connects field sensors, a power meter, PLC logic, HMI screens, alarms, historical storage, and controlled remote access. The dashboard is not limited to visualization; current, voltage, power, energy, frequency, trends, event records, and alarm thresholds are linked to overload detection, supply assessment, disturbance diagnosis, batch-energy evaluation, and maintenance planning. The panel topology and ladder-logic concept provide a basis for detailed engineering, while the proposed validation criteria establish measurable targets for accuracy, refresh rate, command response, alarm response, data completeness, and communication availability. The concept can support safer, more transparent, and energy-efficient livestock production, but its technical performance and economic benefits must be confirmed through component sizing, prototype construction, calibrated testing, and field validation.

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