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Smart Anti-Outage System for Residential Energy Management

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Abstract - This research presents an innovative, self-sufficient power system leveraging Arduino and GSM technologies. By seamlessly integrating solar and grid power sources, the system ensures reliable and uninterrupted power supply, even in remote or grid-constrained locations. Key features include rapid switching between power sources (less than 10 milliseconds), real-time monitoring, and remote control via SMS and mobile application. Intelligent energy management algorithms optimize energy consumption and prioritize essential loads. This system offers a promising solution for both residential and commercial applications, contributing to energy efficiency, reduced reliance on grid power, and environmental sustainability.

Keywords- Smart, Anti-outage, Residential, SIM900, Energy management system.

I. INTRODUCTION

Electricity shortages, increasingly frequent on a global scale, are jeopardizing our comfort and economy. Unscheduled outages, voltage fluctuations, and rising energy costs present numerous challenges. In the face of this situation, traditional power supply solutions are showing their limitations. Autonomous power systems, by freeing themselves from dependence on the electrical grid, offer an attractive alternative.

Our innovative system, based on the Arduino platform and GSM communication, provides a complete and customized solution. It allows the combination of various energy sources, such as solar panels, wind turbines, or generators, to ensure continuous and reliable electrical power. Thanks to intelligent management algorithms, the system optimizes consumption and maximizes energy autonomy [5].

At the heart of our solution, Arduino, an open-source electronic prototyping platform, offers unparalleled flexibility. It enables the design of a tailor-made system, adapted to each need [4]. GSM communication, on the other hand, ensures remote monitoring and intuitive system management via a mobile application [9]. This technological combination not only allows real-time monitoring of the system's status but also enables the receipt of alerts in case of malfunctions or abnormal conditions [8].

The advantages of our system are numerous: continuity of service, reduction of electricity bills, environmental respect, flexibility, and adaptability. Moreover, it offers a sustainable solution to current and future energy challenges. By adopting our system, users can not only reduce their carbon footprint but also safeguard against the uncertainties of the traditional electrical grid [1].

Furthermore, our solution is designed to be scalable, allowing the addition of new energy sources or additional modules over time. This modularity ensures that the system can evolve with the changing needs of users while remaining at the forefront of technology [10].

GSM integration also facilitates SMS notifications, enabling real-time alerts. AT commands, used to control the GSM module, ensure seamless communication with the system. These commands allow for GSM module configuration, SMS exchange, and phone call management, providing comprehensive remote monitoring and control [2].

JIRAMA, the national electricity grid in Madagascar, faces numerous challenges in providing stable and reliable power to its customers. We firmly believe that the future of energy lies in intelligent, autonomous, and environmentally friendly solutions. Our system is designed to meet these requirements and to offer a viable and sustainable alternative to global energy challenges ([3], [6], [7]).

II. MATERIALS AND METHODS

A. Materials

1. Intelligent Control System

An intelligent control system comprises several interconnected components that collaborate to accomplish a specific task. These components interact dynamically to make decisions and adjust their behavior based on information received from the environment. Figure 1 presents a typical architecture of an intelligent control system.

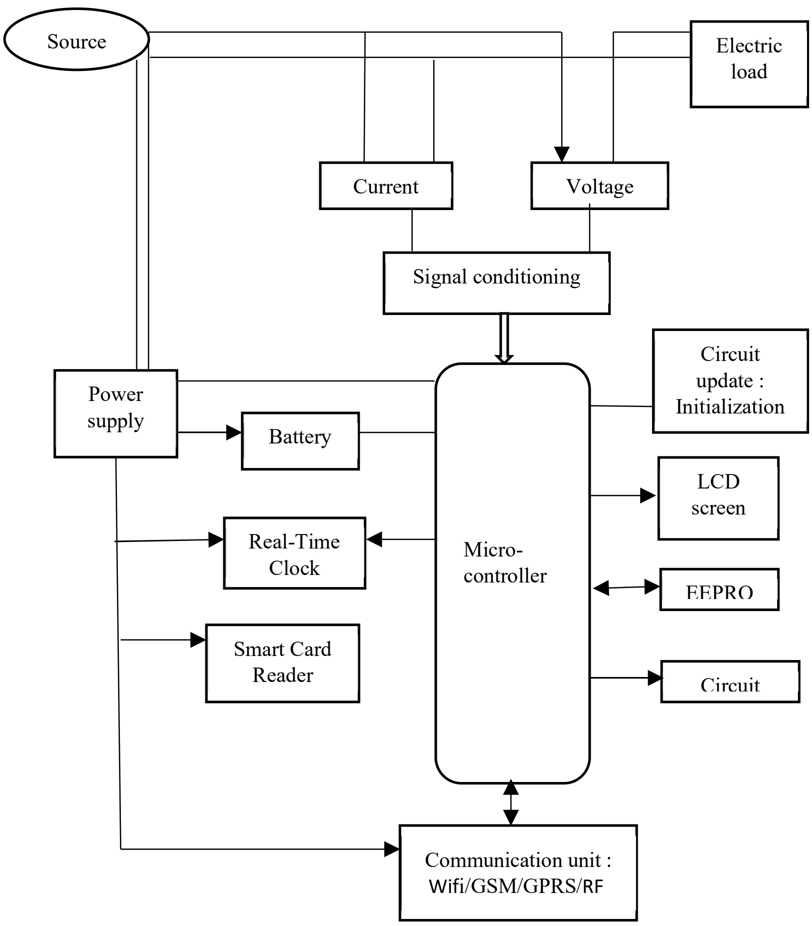

Fig. 1 Intelligent Control System

2. Current Sensor ACS712

The ACS712 Hall Effect sensor is used to measure the current flowing through the load. The sensor outputs a voltage proportional to the current. This voltage is then amplified and converted to a digital value by the microcontroller's analog-to-digital converter (ADC). The microcontroller processes this digital value to calculate the actual current flowing through the load.

The ACS712ELECT-30A model, with its ability to measure currents up to 30 Amperes in both directions and its sensitivity of 66mV/A, is particularly suited to our application. Additionally, its 5V supply and 2.1kV isolation guarantee accurate and safe measurement.

3. Voltage Divider and Rectifier

The voltage divider circuit, consisting of two resistors, is used to scale down the input voltage to a range suitable for the microcontroller's ADC. The rectifier circuit ensures that only the positive half-cycle of the AC voltage is applied to the divider, allowing for accurate measurement of both AC and DC voltages.

4. Microcontroller

The microcontroller serves as the central processing unit of our embedded system. It features an integrated processor, memory, and I/O peripherals. By acquiring data through its input pins, processing it based on the programmed algorithms, and driving the output pins accordingly, it enables the system to operate autonomously.

5. LCD Display

A 2x16 character LCD is employed for textual output. Operating in 4-bit mode, it is interfaced with the microcontroller using the RS, RW, E, and D4 to D7 pins. The Liquid Crystal library provides a convenient abstraction layer for controlling the LCD within the Arduino environment.

6. Actuators

Our system utilizes Arduino relay modules and ABB AF38-30-00-13 contactors as actuators. The relays serve as intermediate control elements, switching the contactors to regulate high-power electrical loads. This hierarchical arrangement ensures electrical isolation and optimized power handling.

7. Development Board: Arduino Uno

The Arduino Uno is an open-source prototyping platform, popular among hobbyists and professionals. It serves as the foundation for numerous electronic projects, ranging from home automation to robotics. At the heart of the Arduino Uno lies an Atmega328P microcontroller, responsible for executing programs. These programs are loaded into the microcontroller's memory via a USB port.

The primary components of the Arduino Uno include:

- Microcontroller: This is the "brain" of the board, executing program instructions and managing input/output operations.
- Memory: This stores the program and data. There is read-only memory (ROM) for permanent storage and random access memory (RAM) for temporary calculations.
- Input/Output: Digital pins control electronic components (LEDs, motors, etc.), while analog pins read analog values (temperature, light intensity, etc.).
- Power Supply: The Arduino Uno can be powered by a USB port or an external power supply.
- Connectors: These allow the Arduino to be connected to other electronic components.

8. GSM SIM900 Module: Wireless Communication Interface

The GSM SIM900 module represents a sophisticated electronic component designed to facilitate wireless communication through mobile networks. This versatile module has become a popular choice for electronic projects requiring SMS messaging capabilities.

In our specific project, we selected this module primarily due to its user-friendly nature and seamless compatibility with Arduino platforms.

The operational framework of the SIM900 module centers around remote control through AT commands transmitted from the Arduino board. These standardized commands enable a wide range of functionalities, including module configuration, SMS message transmission, call management, and various other communication features. Through this robust communication interface, the Arduino gains the ability to interact with the external world via mobile network infrastructure.

The module boasts several key features that make it particularly valuable for electronic projects. Its design specifically accommodates Arduino compatibility, ensuring straightforward integration with Arduino-based systems. The module excels in SMS communication capabilities, offering both sending and receiving functionalities. Its control system relies on standardized AT commands, providing a reliable and well-documented interface. Furthermore, its compact physical design facilitates easy integration into various project configurations.

In our specific project implementation, the SIM900 module serves multiple crucial functions. It acts as an alert system, capable of sending SMS notifications to users when specific events occur. The module also enables remote device control, allowing users to activate or deactivate Arduino-connected devices through specific SMS commands. Additionally, it serves as a data collection interface, facilitating the transmission of sensor-measured data to remote servers for analysis and monitoring purposes.

B. Methods

1. Serial Interface: Arduino-GSM Link

The communication between the Arduino board and the GSM shield is established through a serial interface, which is implemented using a dual-jumper system. This system provides users with the flexibility to choose between two distinct communication methods: a software serial link or a hardware serial link.

The software serial link approach requires the implementation of the SoftwareSerial.h library within the Arduino program. While this method offers significant flexibility in terms of pin selection for communication, it does come with the trade-off of higher processor resource consumption. Conversely, the hardware serial link method utilizes the Arduino's dedicated hardware serial pins (TX and RX), providing enhanced speed and improved resource efficiency.

Regardless of which communication method is selected, proper configuration of the serial link is crucial. The system requires a specific communication speed of 19200 bits per second, which must be explicitly defined within the Arduino code to ensure reliable data transmission between the components.

The operational status of the GSM module is continuously monitored and displayed through a system of three LED indicators. These LEDs serve as visual indicators of the module's current state, allowing users to quickly assess the system's functionality and identify potential issues (Table I). Each LED provides specific information about different aspects of the module's operation, making troubleshooting and status monitoring more intuitive and efficient.

Table I. GSM Module Status Indications

	LED State	System Event
LED ("PWR" green)	Off	Shield is off
	On	Shield is powered on
LED ("STATUS" red)	Off	SIM900 module is off
	On	SIM900 module is powered on
LED ("NETWORK" green)	Off	SIM900 module is in sleep mode
	On : 64ms ; Off : 800ms	Module cannot find network
	On : 64ms ; Off : 3000ms	Module has found a network
	On : 64ms ; Off : 300ms	GPRS communication

1. Actuators: Controlling and Monitoring Loads

Actuators are electronic or electromechanical components that perform physical actions in response to specific commands. In our system, they serve two main functions.

First, actuators enable power supply control. They have the ability to cut off or restore the main power supply, such as that provided by JIRAMA. This function is essential for managing energy supply in a secure and efficient manner.

Second, these devices are responsible for activating and deactivating electrical loads. Specifically, they can turn various electrical devices on or off as needed. This functionality allows for precise and automated management of equipment connected to the system.

2. Control Architecture: A Two-Stage Power Management System

Our system employs a sophisticated two-stage architecture designed to ensure electrical isolation and efficient power management.

The first stage consists of the control system, centered on an Arduino relay module. This integrated circuit incorporates multiple relays and is managed by an Arduino UNO microcontroller. The module features several digital inputs (labeled IN1, IN2, IN3, and IN4) that can be configured to either a high (HIGH) or low (LOW) state. When set to LOW, the relay contact closes and permits current flow. Conversely, when set to HIGH, the relay contact opens and interrupts the current flow. This module is capable of handling voltages up to 250 VAC and currents up to 10A, making it suitable for controlling substantial electrical loads.

The second stage comprises the power management system, which utilizes the ABB AF38-30-00-13 contactor. This electromagnetic contactor is specifically designed for high-power applications and is controlled by the outputs from the Arduino relay module. The contactor plays a crucial role in managing high currents, with the capability to handle up to 10A at 250 VAC. The ABB AF38-30-00-13 contactor features impressive technical specifications, including operation with coil voltages ranging from 100 to 250 VAC, compatibility with frequencies of 50-60 Hz, and the ability to handle maximum voltages of up to 600 VAC.

3. LCD Display: Principle and Usage

Liquid Crystal Displays (LCDs) represent a fundamental technology in electronic information display. These components are widely implemented for presenting both textual and graphical information, with their popularity largely attributed to their remarkable energy efficiency, typically consuming only 1 to 5 mA of power.

The operating principle of an LCD revolves around its pixel-based structure. Each display consists of numerous pixels that can be individually controlled to create characters or images through precise electrical signaling. The functionality of an LCD is managed through several essential pins, each serving a specific purpose. The Register Select (RS) pin determines the nature of the transmitted byte, distinguishing between commands (RS=0) and displayable characters (RS=1). The Read/Write (RW) pin specifies whether the operation involves writing data to (RW=0) or reading data from (RW=1) the display memory. The Enable (E) pin serves to validate the transmission of each byte.

The power management of the LCD is handled through three crucial pins: VSS for ground connection, VEE for contrast voltage control (which affects character brightness), and VDD for power supply. Additionally, eight data pins (D0 through D7) facilitate the transmission of information to the display.

For our specific application, we have implemented a 2x16 character LCD operating in 4-bit mode. This configuration means that data transmission to the display occurs in two distinct steps, utilizing only pins D4 through D7. This approach optimizes the pin usage while maintaining full functionality of the display system.

C. Software Part and Control

1. Arduino Development Environment (IDE)

The Arduino Integrated Development Environment (IDE) is a software that allows you to program Arduino boards. It offers an intuitive user interface, divided into several main areas (Fig. 2):

- Menu bar: Contains software configuration options such as preferences, tools, and example programs.
- Toolbar: Groups the most commonly used buttons for compiling, uploading the program, creating new files, etc.
- Code editor: This is where you write your Arduino code.

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- Console: Displays compilation messages, errors, and the results of program execution.

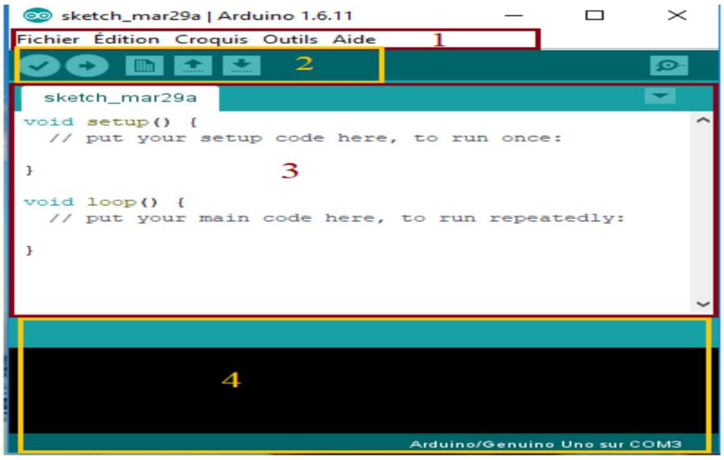

Fig.2: Arduino Development Environment Interface

Detailed description of the buttons (Fig.3):

- Verify/Compile: Analyzes your code for syntax errors.
- Upload: Transfers the compiled program to the Arduino board.
- New: Creates a new program file.
- Open: Opens an existing program file.
- Save: Saves the currently edited program.
- Serial Monitor: Opens a window to display data sent by the Arduino board.

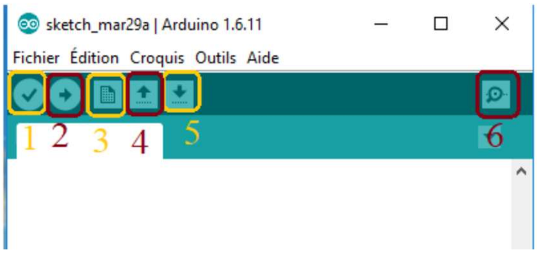

Fig. 3: Arduino Interface Buttons

2. AT Commands

AT commands are a set of codes used to communicate with modems or GSM modules. Each instruction begins with the sequence "AT" and ends with a carriage return character "CR". This protocol allows communication between a Terminal Equipment (TE) such as a microcontroller and a Modem Equipment (ME) like a mobile phone, via a serial interface. The operation of AT commands is based on an exchange of text messages. When the TE sends an AT command, the ME processes this request and returns a response indicating the result of the operation.

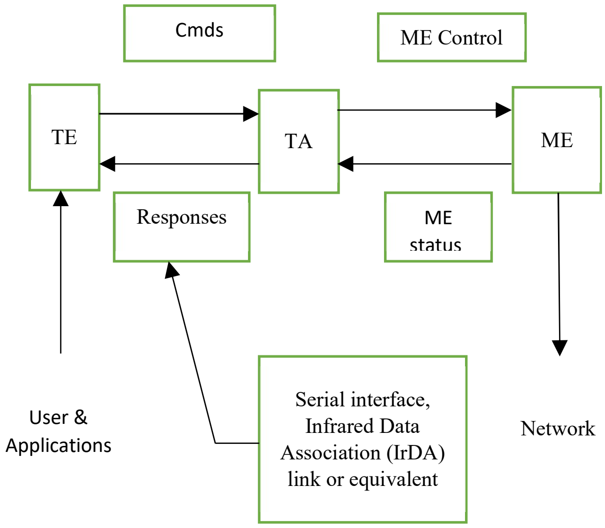

Fig.4 AT command process

This diagram illustrates the communication process between a Terminal Equipment (TE) and a GSM modem or module (Mobile Equipment - ME) using AT commands.

The process begins when a user or application sends an AT command through the Terminal Equipment. The TE then transmits this command to the Terminal Adapter (TA).

Upon receiving the command, the TA translates it into a format that can be understood by the Mobile Equipment and forwards it accordingly. The ME processes the command and sends a response back to the TA.

Following this, the TA relays the response to the TE, which then displays the response to the user or application.

AT commands provide a simple text-based interface that allows equipment (such as a microcontroller) to communicate with a modem or GSM module. This diagram effectively demonstrates the various entities involved in this process and the information exchanges that take place between them.

AT commands are categorized into two main groups according to GSM standards:

- GSM 07.07: This standard defines a comprehensive set of commands for controlling all features of a GSM module, from call management to network configuration.
- GSM 07.05: This standard specifically focuses on SMS-related functionalities, providing a set of commands dedicated to sending, receiving, and managing short messages.

Table II. Main AT commands for the GSM module

Command	Function
AT+CGMM	Model identification
AT+CGMR	Revision identification
AT+CGSN	Serial number (IMEI) identification
AT+CIMI	International Mobile Subscriber Identity (IMSI) information
AT+CLIP	Caller ID presentation
AT+CSCS	Alphabet used by the TE
AT+CPAS	Power supply status
AT+CPIN	Enter PIN code
AT+CBC	Battery charge status
AT+CREG	Network registration status

AT+CSQ	Signal quality
AT+CIND	Call indicators
AT+CPBS	Select a phonebook
AT+CPBR	Read the phonebook
AT+CPBF	Search for an entry in the phonebook
AT+CPBW	Write to the phonebook
AT+CCLK	Clock
AT+CALA	Alarm
AT+CMEE	Error reporting

Table III. AT Commands for SMS Management

Command	Function
AT+CSMS	Select message service
AT+CPMS	Select memory area for SMS storage
AT+CMGF	Select SMS format (PDU or TEXT)
AT+CSCA	Set the address of the service center
AT+CSDH	Display SMS settings in TEXT mode
AT+CSAS	Save settings
AT+CRES	Restore default settings
AT+CNMI	New SMS indication
AT+CMGL	List stored SMS
AT+CMGR	Read an SMS
AT+CMGS	Send an SMS
AT+CMSS	Send a stored SMS
AT+CMGW	Write an SMS
AT+CMGD	Delete an SMS
AT+CPBR	Read the phonebook
AT+CPBF	Search for an entry in the phonebook
AT+CPBW	Write to the phonebook

III. PRACTICAL IMPLEMENTATION OF THE ANTI-LOAD-SHEDDING SYSTEM

This section presents the practical implementation of the anti-load-shedding system based on a modified sine wave inverter. The system assembly includes the connection of the inverter, batteries, Arduino microcontroller, sensors, and various control elements. The microcontroller manages the switching between the main electrical network and the inverter based on the information provided by the voltage and current sensors. Tests have been carried out to verify the reliability and efficiency of the system by simulating various operating conditions, including prolonged power outages and load variations.

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A. SIM Card Installation

In order to enable remote monitoring and control of our system via SMS, an active SIM card must be inserted into the slot provided on the GSM module. Fig. 5 illustrates this operation.

Fig.5 SIM card installation in the GSM module

B. GSM Module Connection and Power Supply

The GSM module is connected to the Arduino Uno board by overlapping the two boards and connecting the corresponding pins. To power the system, we use :

- A 12V 2A power supply for the GSM module. This power supply turns on the module's "POWER" LED as soon as the system is powered on.
- A 5V power supply for the Arduino Uno.

Initialization and verification: After powering on the system, the "STATUS" LED should turn on to indicate that the module is operational. Additionally, the "NETWORK" LED should blink if the module has detected a mobile network. To reset the module, simply press the "POWER" button for about 2 seconds.

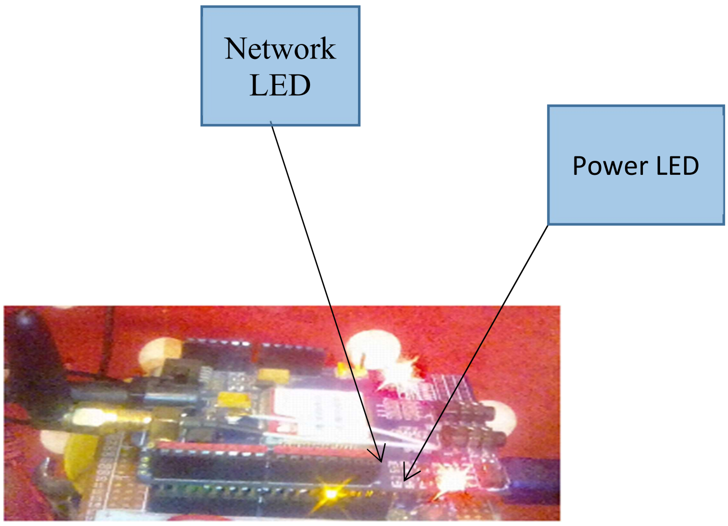

Fig.6 Hardware configuration of the SIM900 GSM module on Arduino Uno

A close-up view of the Arduino Uno board with the installed SIM900 GSM module. The "NETWORK LED" and "POWER LED" indicate the network connection status and module power status, respectively. The connections between the different components are clearly visible.

C. Energy Storage Management

1. Core Energy Management Algorithm

The energy management algorithm is at the heart of our system, ensuring optimal battery usage and maximizing system efficiency.

```
START
 DECLARE pins and variables:
  I  // Current
  Ub // Battery voltage

 IF Ub > 12V THEN
  // Proceed with operations requiring a battery voltage above 12V
  // For example:
  // Activate a relay
  // Start a motor
  // ...
 ELSE
  // Disable the battery
  // For example:
  // Deactivate a relay
  // Turn off a power supply
  // ...
 END IF
END
```

2. Validation of Direct Current Current and Voltage Sensors

A test protocol involving a 10kΩ potentiometer was employed to assess the performance of the DC current and voltage sensors. This potentiometer facilitated the adjustment of the voltage applied to the energy storage device within a range of 0 to 15V. Concurrently, a lamp was incorporated to provide visual feedback on the charging process.

By incrementally modifying the potentiometer setting, variations in the voltage measured by the voltage sensor were observed. Upon reaching the predefined voltage threshold of 11V, the energy management system, utilizing data from the sensor, initiated an automatic cessation of charging for the series-connected supercapacitor bank. This safety mechanism safeguards against excessive supercapacitor discharge and prolongs their operational lifespan.

Figure 8 presents the experimental outcomes, depicting the temporal evolution of the current injected into the supercapacitors and the voltage across the energy storage device.

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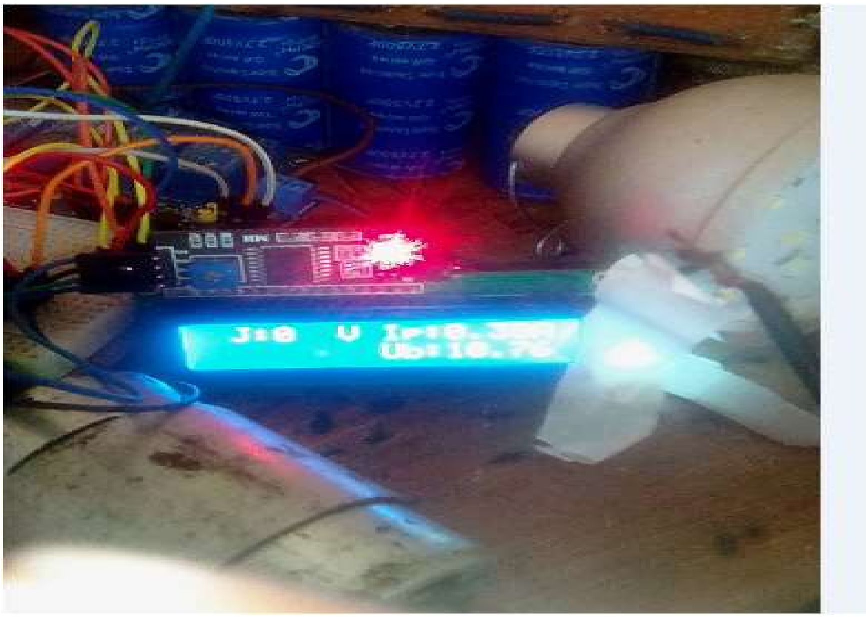

Fig. 7 Real-time visualization of supercapacitor charging data on an LCD screen

To quantify the energy stored within the supercapacitor at any specific juncture, measurements of the injected current and voltage across the component were conducted during the charging phase. The data collected over a six-minute period indicates an average current of 0.63A supplied by the ACS712. Considering the charging adapter's specifications of 12V and a maximum current of 2A, an approximate energy storage of 0.756 Wh can be inferred (calculated via the formula: Power = Voltage × Current × Time). This energy capacity proved adequate to sustain a 12V, 9W lamp for over five minutes, thereby validating the correlation between the energy

To expedite the charging process, augmenting the power output of the energy source is a viable approach. The implementation of a suitably sized photovoltaic (PV) panel exemplifies this strategy. Such a methodology is indispensable for mitigating potential energy deficiencies relative to consumption demands.

Table IV. Real-time Data Log of Voltage and Current during Supercapacitor Charging

Time	Input Current (A)	Supercapacitor Voltage (V)
22:54:31.382	0.60	10.967
22:55:21.429	0.60	11.27
22:55:33.782	0.48	11.32
22:56:36.120	0.39	
22:56:36.167		11.85
22:57:38.505	0.50	11.97
22:58:40.842	0.56	11.97
22 :59 :42.197	0.58	11.97
22 :00 :45.518	0.69	11.97

This table presents the serial monitor output, displaying the measured voltage across the supercapacitor and the charging current over time. The data is collected and displayed in real-time using an Arduino microcontroller.

A series of measurements were conducted to characterize the AC voltage sensor. By varying the input voltage supplied by the JIRAMA grid, the corresponding output voltages were recorded.

Table V. Static characteristics of the AC current sensor

JIRAMA Grid Input Voltage (V)	Measured Output Voltage (V)	Calibration Coefficient	Calculated Output Voltage (V)
246	4.73	52.00845666	5
230	4.4	52.27272727	4.674796748
220	4.2	52.38095238	4.471544715
200	3.82	52.35602094	4.06504065
180	3.43	52.47813411	3.658536585
160	03.03	52.80528053	3.25203252
140	2.65	52.83018868	2.845528455
120	2.22	54.05405405	2.43902439
100	1.84	54.34782609	2.032520325
80	1.52	52.63157895	1.62601626
60	1.25	48	1.219512195
40	1.14	35.0877193	0.81300813
20	0.82	24.3902439	0.406504065
10	0.66	15.15151515	0.203252033

These data allow for plotting the sensor's response curve and evaluating its sensitivity and linearity within the considered measurement range, the sensor exhibits a linear response over the tested range.

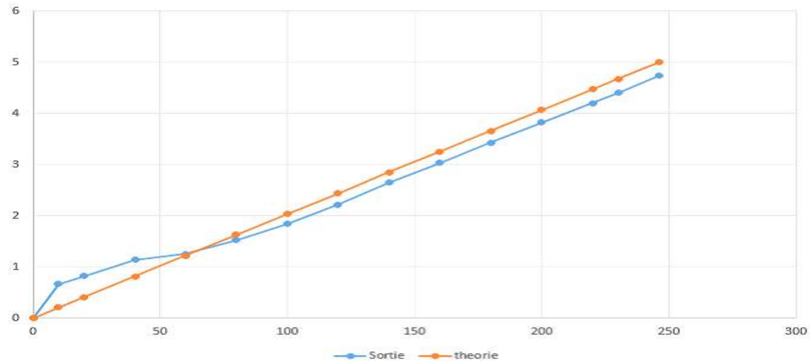

Fig. 8 AC Voltage Sensor Linearity Characteristic

Sensor Calibration and Performance: A strong linear relationship was observed between the input and output voltages, with a mean transfer coefficient of 52.5 V/V. The sensor exhibited high sensitivity, with a measured value of 20 mV/V. A comparative analysis revealed a low average error of 6.38%, indicating excellent accuracy.

Anti-Blackout System: The proposed anti-blackout system employs a highly sensitive voltage sensor to ensure reliable power supply. This sensor's precise linear response and high sensitivity enable accurate voltage monitoring, facilitating timely detection of voltage drops and subsequent activation of backup power sources.

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D. System Implementation and Commissioning

This section describes the process of building and testing the intelligent load shedding system, from hardware assembly to software configuration.

1. Implementation of the System

a. Proteus Circuit Simulation

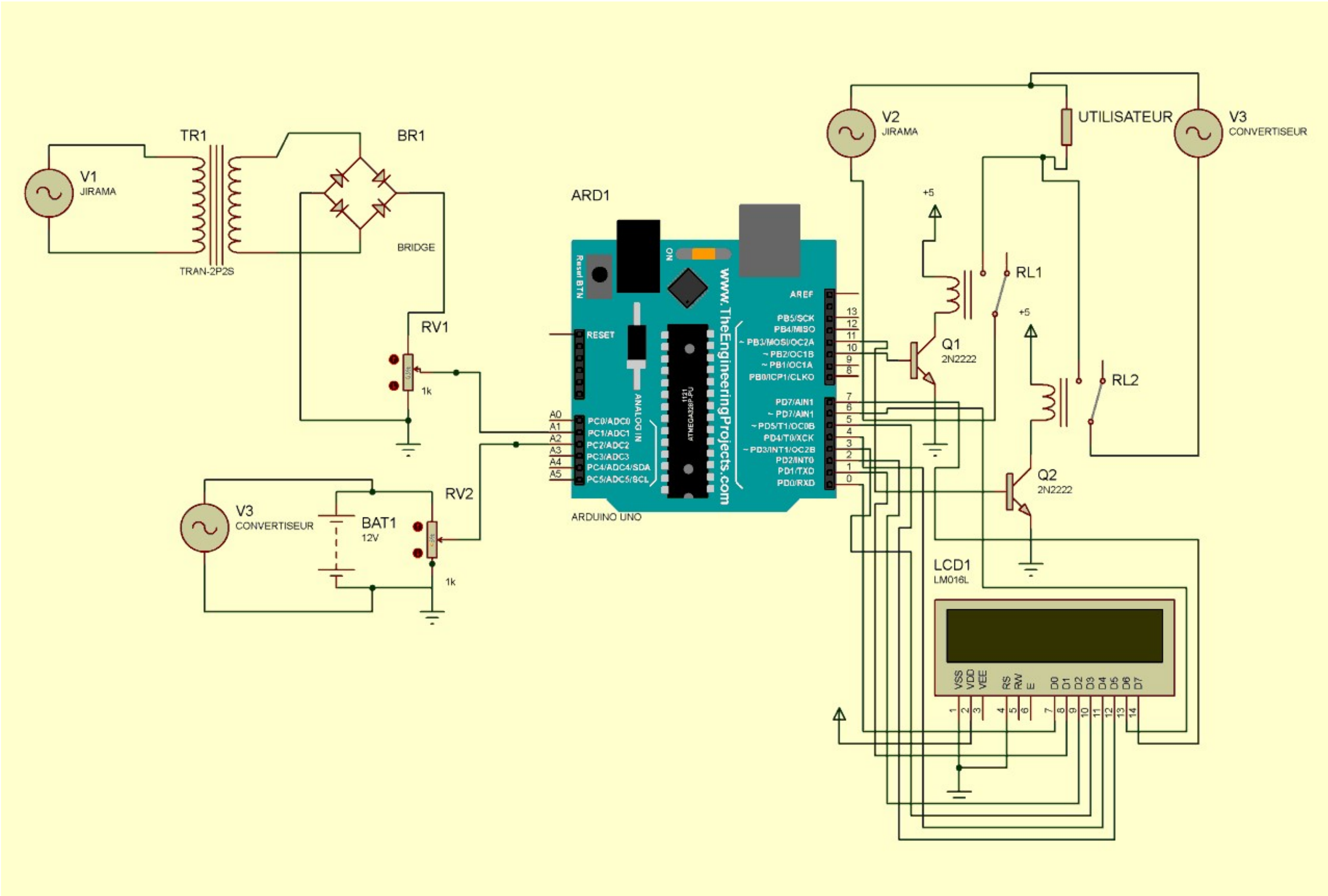

Fig.9 Proteus simulation model of the anti-blackout system

To simplify the schematic, we have chosen a standard configuration:

- The Ethernet Shield is directly stacked on the Arduino Uno, using the dedicated pins.
- The GSM Shield is connected to the Arduino Uno as follows:
- GSM TX to Arduino RX: Arduino pin 8.
- GSM RX to Arduino TX: Arduino pin 7.
- Power supply: GSM Vcc connected to Arduino 5V, and GSM GND connected to common ground.

This configuration allows for direct serial communication between the Arduino and the GSM module. Note: TX stands for Transmit, RX for Receive, and GND for Ground.

b. Pin Configuration of Components Connected to the Arduino Uno in the Anti-Load Shedding System

Table VI. presents the pin assignments for components such as temperature sensors and actuators connected to the Arduino Uno. This table is essential for the electronic assembly and proper operation of the system.

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Table VI. Power Management System I/O Configuration

I/O Peripheral	Pin Number	Type	Functionality
Solar Panel Current Sensor (Shunt)	A0	Analog (mA)	Measures the current produced by the solar panels
Utility Voltage Sensor	A1	Analog (V)	Measures the voltage of the JIRAMA electrical grid
Battery Voltage Sensor	A2	Analog (V)	Measures the battery voltage
Solar Panel Switch	10	Digital	Controls the on/off state of the solar panel
Utility Switch	11	Digital	Controls the on/off state of the utility grid connection
Load Switch	12	Digital	Controls the on/off state of the electrical load

The system is a hybrid solar-utility power system with battery backup. The system monitors the solar panel current, utility voltage, and battery voltage to optimize power usage and ensure a reliable power supply.

I/O Peripheral Breakdown:

- Solar Panel Current Sensor (Shunt):
  - Analog Input: The current sensor outputs an analog voltage proportional to the current flowing through the solar panel.
  - Microcontroller Role: The microcontroller reads this analog voltage and converts it into a current value using the sensor's calibration factor.
  - Purpose: Monitors the solar panel's power output to optimize energy harvesting and system efficiency.
- Utility Voltage Sensor :
  - Analog Input: This sensor measures the voltage supplied by the utility grid.
  - Microcontroller Role: The microcontroller reads this voltage and compares it to a reference value to determine if the utility power is reliable.
  - Purpose: Ensures a seamless transition between solar power and utility power.
- Battery Voltage Sensor :
  - Analog Input: This sensor monitors the voltage level of the battery.
  - Microcontroller Role: The microcontroller reads the battery voltage to determine its state of charge and to decide when to charge or discharge it.
  - Purpose: Manages the battery's charge and discharge cycles to optimize its lifespan and performance.
- Solar Panel Switch :
  - Digital Output: This switch controls the connection of the solar panel to the system.
  - Microcontroller Role: The microcontroller can turn the switch on or off based on various factors, such as solar irradiance, battery state of charge, and utility power availability.
  - Purpose: Enables or disables the solar panel's contribution to the system.
- Utility Switch :
  - Digital Output: This switch controls the connection to the utility grid.
  - Microcontroller Role: The microcontroller can turn the switch on or off based on factors like grid reliability, solar power availability, and battery state of charge.
  - Purpose: Manages the system's reliance on the utility grid.

- Load Switch :
  - Digital Output: This switch controls the connection of the load to the power source.
  - Microcontroller Role: The microcontroller can turn the switch on or off based on the availability of power from the solar panel, battery, or utility grid.
  - Purpose: Ensures a reliable power supply to the load, prioritizing different sources based on their availability and efficiency.

By effectively utilizing these I/O peripherals and the microcontroller's processing capabilities, the system can achieve optimal power management and energy efficiency.

2. System Operation Principle

Our anti-load shedding system functions through a coordinated interplay between several key components: the user, GSM module, Arduino microcontroller, sensors, and actuators.

a. User Interaction

The user interacts with the system via SMS commands sent to the GSM module. These commands trigger specific actions and request system information.

b. GSM Module Communication

The GSM module acts as a wireless bridge between the user and the Arduino. It receives SMS messages, decodes them, and transmits the instructions to the Arduino via serial communication using AT commands. Additionally, the module sends requested information back to the user.

c. Arduino Microcontroller Control

The Arduino microcontroller serves as the system's central processing unit. It receives commands from the GSM module and executes them based on sensor data and predefined algorithms. Its primary functions include:

- Power Management: The microcontroller intelligently manages the system's power supply, switching between mains power and battery power as needed.
- Actuator Control: It controls relays to activate or deactivate connected devices, such as appliances or lighting systems.

d. Sensor Feedback

Sensors continuously monitor the system's status, including battery voltage and mains power availability. This sensor data is relayed to the microcontroller to inform decision-making.

e. Actuator Response

Actuators, such as relays, execute commands from the microcontroller. These commands may involve switching on or off specific devices or adjusting system settings.

f. Cyclic Operation

The system operates in a cyclical manner:

- User Input: The user sends an SMS command.
- GSM Module Reception: The GSM module receives the command.
- Arduino Processing: The Arduino analyzes the command, consults sensor data, and determines the appropriate action.
- Actuator Activation: The Arduino sends instructions to the actuators to execute the command.
- Feedback (Optional): The GSM module may send a confirmation message or system status update to the user.

This cyclical process ensures continuous monitoring, control, and optimization of the system's performance.

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IV. RESULTS

After conducting a thorough simulation using Proteus, we were able to validate the performance and reliability of our anti-outage system. The results demonstrate the system's capability to manage various energy sources efficiently, ensuring continuous and stable power supply.

The following figure illustrates our innovative anti-outage system, designed to ensure continuous and reliable power supply by integrating various energy sources and advanced control strategies.

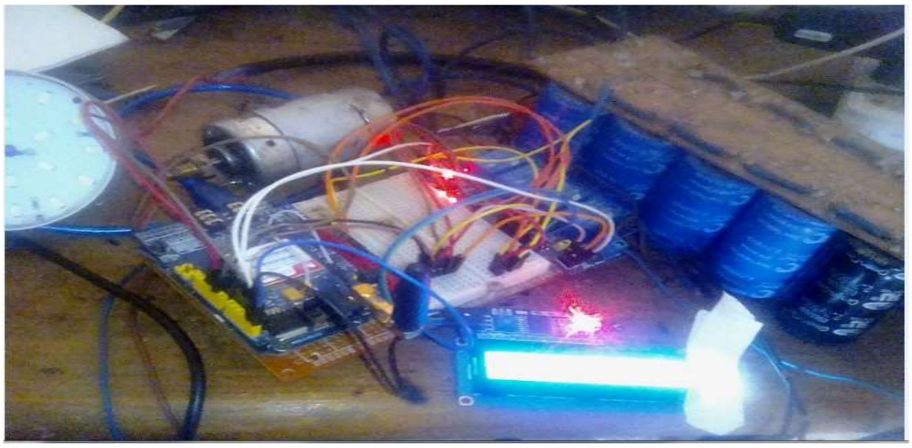

Fig. 10 Our Anti-Outage System

The developed system has demonstrated significant advancements in ensuring continuous power supply, optimizing energy consumption, and enhancing user convenience. These improvements are achieved through innovative features such as load shedding management, battery voltage monitoring, and remote energy management.

A. Improved Service Continuity

The results obtained demonstrate that the developed system offers an effective solution for ensuring service continuity during power outages, optimizing energy consumption, and facilitating remote management of installations. The system ensures a continuous power supply during JIRAMA outages by promptly detecting interruptions and automatically switching to solar power. This feature minimizes service interruptions and enhances reliability.

B. Optimized Energy Consumption

Real-time monitoring of energy production and consumption optimizes solar energy utilization and reduces energy costs. Users can track their energy usage and adjust their consumption patterns accordingly.

C. Ease of Use

Remote management via SMS empowers users to monitor and control their system anytime, anywhere. This feature enhances user convenience and ensures timely intervention in case of issues.

D. Inverter Roles

The inverter is essential for managing power supply interruptions and optimizing energy usage. It facilitates seamless transitions between power sources and provides continuous monitoring of battery voltage and energy consumption.

1. Load Shedding Management

When the main power supply (JIRAMA) is interrupted, a sensor detects this and automatically switches to solar power after a 10-millisecond delay. The battery voltage is displayed on an LCD screen. Upon restoration of the main power supply, the system automatically reverts to mains power.

2. Battery Voltage Monitoring

To ensure optimal management of stored energy, the battery voltage is continuously monitored. When the voltage reaches a critical threshold, an alert SMS is sent to a mobile phone. Users can also query the battery voltage via SMS. The same principle applies to the power delivered to consumers.

3. Remote Energy Management

This prototype enables remote management of energy production and consumption. Real-time monitoring of various parameters facilitates the optimization of solar energy usage and stored energy. In case of energy shortages, the system can prioritize power to essential loads.

V. CONCLUSION

The anti-outage system presented in this research offers a significant advancement in residential power management. By seamlessly integrating solar power and advanced control strategies, this system provides a reliable, efficient, and sustainable solution to power supply challenges. Key features such as rapid response times, real-time monitoring, and remote control, coupled with intelligent energy management algorithms, ensure optimal system performance and user convenience.

The system's potential to contribute to the broader goal of smart city development is substantial. By optimizing energy consumption, reducing reliance on traditional grid infrastructure, and enhancing energy security, this technology can play a pivotal role in creating more sustainable and resilient communities.

While the current prototype demonstrates promising results, further research and development efforts are necessary to explore advanced features like predictive maintenance, enhanced cybersecurity measures, and integration with emerging technologies such as the Internet of Things (IoT) and artificial intelligence. These advancements could further elevate the system's capabilities and contribute to a more sustainable and resilient energy future.

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