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Smart Energy Switching System Using Arduino: Application to a Model Farm

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Dedication   الإهداء

إلى كل من كانت دعواتهم سلاحا خفيا يحميني في صمتي...

إلى من سهروا الليالي ليروا هذه اللحظات تزهر..

إلى من غرسوا في قلبي الصبر، وفي عقلي الطموح.....

إلى والدي العزيز، ووالدتي الغالية

أنتم النور الذي أنار طريقي للوصول الى هاته اللحظة, والسند الذي أسندت ظهري عليه وأنا مغمض العينيين

لكما أهدي ثمرة هذا الجهد ونجاحي الذي لا يوف الا القليل من فضلكما علي

إلى أخوتي وأخواتي وأصدقائي وكل عائلتي

ضحكاتكم، دعمكم، وجودكم، ..... كل ذلك كان بلسم كل تعب

إلى أساتذتي الكرام وكل من علمني حرفا

لكم أسمى وأعظم عبارات الشكر والامتنان على كل علم وحرف علمتمونا إياه

كل توجيهاتكم كانت جوهرة في نجاحنا

والشكر الخاص الى إخوتي في الجمعيات والنوادي وأخص بالذكر خليتي "عدسة وآرتزي"

أنتم أكثر من رفاق الدرب ... أنتم ذكرى جميلة ستبقى محفورة في قلبي

شكرا على كل لحظة، على كل دعم، على كل ابتسامة، على كل شيء

لقد كنتم الإلهام والدعم الكبير لي في هذا النجاح المبارك

أخوكم في الله ومحبكم فيه "إدريس صويلحي"

Dedication

الإهداء

إلى من غرسا في قلبي الأمل،

إلى من سهرا الليالي لأجل أن أنجح،

إلى من كانت دعواتهم سر توفيقي...

إلى أمي وأبي،

لكما كل الحب، وكل الامتنان، وكل ما أنجزته وما سأحققه مستقبلاً هو ثمرة تعبكما ودعمكما اللامحدود.

إلى إخوتي وأخواتي، سندي في الحياة،

إلى أصدقائي الذين كانوا دومًا في الصف الأول لتشجيعي،

إلى كل من علّمني حرفًا، أو فتح لي بابًا من أبواب المعرفة،

إلى مشرفي الفاضل، الذي لم يبخل علي بنصائحه وتوجيهاته،

أهدي ثمرة هذا الجهد المتواضع، راجيًا أن يكون بداية لمسيرة علمية ومهنية واعدة بإذن الله.

أخوكم في الله "نبيل شنين"

Thanks تشكرات

من لا يشكر الناس لا يشكر الله

نتوجه بعظيم الشكر والعرفان الى كل من

والدينا الكريمين السند الكبير لنا في هذه الحياة

الى أخوننا وأخواتنا والى كل أقاربنا دعمكم شكرا على كل دعم قدمتموه لنا

الى أستاذنا الكريم "خنطوط عبد القادر" والأستاذة "عبادة زهور" الذين سهروا معنا

في سبيل نجاحنا في العمل المتواضع

الى أعز أصدقائنا الذين وقفوا معنا جنبا الى جنب في رحلة نجاحنا هاته

الى كل من نخصهم بجليل الشكر والعرفان

نشكركم على كل دعم وعلى كل كلمة وعلى كل ابتسامة وعلى كل معلومة قدمتموها في سبيل

نجاح هذا العمل المبارك

جزاكم الله كل خير وجعلها في ميزان حسناتكم ان شاء الله

Sommer

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Nomenclature

Symbol	Designation	Unit
Fritzing	The Fritzing application is an Electronic Design Automation software with a low entry barrier, suited for the needs of makers and hobbyists. It offers a unique real-life "breadboard" view, and a parts library with many commonly used high-level components	
GotFut	Watering system	
PCB	Polychlorinated biphenyls (PCBs) are persistent organic pollutants, substances that break down very slowly in the environment and accumulate in various media, particularly soil	
Sirocco	A type of wind	

Abbreviation

Symbol	Designation	Unit
Arduino IDE	Integrated Development Environmen	
DC	(DC, Direct Current)	
E	Daily Energy Consumption	Kwh
GPV	photovoltaic generator	
GSM	Global System for Mobile communication	
H	Daily Operating Hours	h
IRES	Institute of Economic and Social Research	
LCD	liquid crystal display	
MPPT	Maximum Power Point Tracking	
P	Power	Kw
PPM	point of maximum power	
PV	Photovoltaic	
PWM	Pulse Width Modulation	
RUl	Light Dependent Resistor	
SOH	State of Health	

General introduction

General Introduction:

In light of the growing challenges facing the energy sector—particularly in rural and isolated areas—there is an urgent need for alternative and intelligent solutions that ensure reliable electricity supply while reducing reliance on the public grid. Among the most promising approaches are hybrid energy systems that combine solar power, the electrical grid, and battery storage, especially when managed by smart control mechanisms that enable efficient energy management.

This thesis aims to design and implement a smart hybrid energy management system based on an Arduino control unit. The system automatically switches between solar energy, the grid, and batteries based on source availability and performance, ensuring continuous and automatic power supply to priority loads under all circumstances.

The Ben Sassi Olive Farm, located in Ouargla Province, was selected as a case study due to its rural nature and its heavy reliance on energy for various agricultural activities.

The thesis is organized into three main chapters:

- **Chapter One** presents the theoretical background of the project, including key concepts related to solar energy, backup power systems, batteries, and an introduction to the Arduino platform. It also includes a review of related previous studies.
- **Chapter Two** is dedicated to the technical study of the proposed system, describing the system's architecture, hardware components, control logic, and programming approach, along with the necessary technical calculations and design considerations.
- **Chapter Three** addresses the practical application through a case study on the Ben Sassi Farm. It includes an analysis of energy consumption, the geographical and climatic context, the development of a scaled prototype, and evaluation of the system's performance through real-world testing.

Overall, this study aims to provide an effective, low-cost, and field-applicable solution that can be expanded and adapted to benefit rural areas suffering from limited access to energy.

Chapter I:

Introduction Of Background Study

I.1. Introduction:

Electricity is one of the most important parts of modern life because it is connected to almost everything people do, from simple daily tasks the most complicated industrial and technological systems. As the world's need for energy grows, there is a greater need to use alternative and sustainable sources that help keep energy secure have less of an effect on the environment. In this setting, photovoltaic solar technology has come a long way thanks to better solar cell characteristics and better efficiency in turning sunlight into electricity.

This chapter is all about studying photovoltaic energy as one of the best options we have. It does this by talking about the physical phenomenon that makes it work, the primary types of solar cells, and their basic electrical properties.

I.2. General Introduction to Renewable Energy

I.2.1. Energy Issues in Remote Areas

The majority of the world's population lives in remote rural areas with low power demand and no utility grid, which hinders overall development. Electricity is a clean and sustainable option for these areas. Renewable energy resources are seen as unlimited, inexhaustible, and environmentally friendly. Benefits of electricity generation from these sources include irrigation, food preservation, crop processing, cooling, and small-scale industries. However, the availability of renewable energy sources is highly variable and site-specific. To overcome this variability, large renewable power plants, energy storage facilities, and integrated renewable energy systems (IRES) can be installed, making them the best options for energizing remote rural areas with electricity in a decentralized mode. [1]

The modern development of energy systems is characterized by rapid growth in the installed capacity of renewable energy sources. Currently, the total installed renewable energy capacity in the world is over 3064 GW, where the wind energy sector has 825 GW and the solar energy sector has 849 GW—Figure 1. The rest relates to hydropower and other sources of renewable energy. This situation is the result of the following main factors: the reduced environmental impact of traditional coal/gas-fired generation; the decrease in the specific cost of installed capacity of solar panels and wind turbines; and the creation of support mechanisms for the development of private, environmentally friendly microgeneration. [2]

Increasing the concentration of carbon dioxide in the atmosphere is one of the key factors for the use of renewable energy sources around the world. The historic "Kyoto Protocol" (1997) and its successor, the "Paris Agreement" (2015), are the main catalysts for the deep integration of renewable energy sources into centralized and autonomous energy systems. In addition, various countries are developing their own programs that promote the development of renewable generation, such as feed-in tariffs, green certificates, free connection to the energy system, guaranteed price and purchase of generated energy, tax incentives, and various other preferences. Such processes create a favorable investment climate for the development of renewable energy. [2]

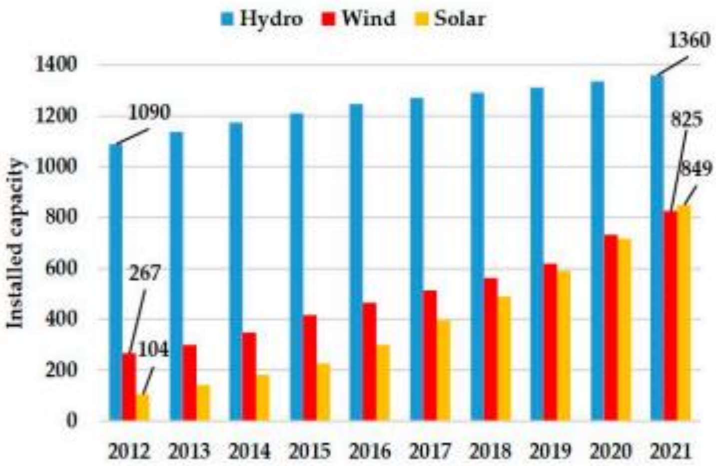


Figure I.1 Renewable energy sources installed capacity[2]

I.2.2. Importance of Research

There is no hesitation in saying that people are becoming increasingly conscious of the importance of using renewable sources of energy, but still a lot of work needs to be done in this domain. For instance, awareness programs must be started in various regions by local engineers and scientists to make people responsive to the importance of alternative energy technologies. They must also discourage them from using fossil fuels due to their evident demerits to the environment and living beings. Courses on renewable sources must be made compulsory to students at school, college, and university levels in order to make them realize their significance and to increase their knowledge in this sphere. The governments should revise the power policies to cope with the energy crisis and to make full use of renewable energy sources. Innovative solutions must be brought by experts in the field to solve the energy catastrophe. Technology exchange programs must be initiated by developed countries in order to help the developing countries to establish, build, and reinforce the renewable energy sector. [3]

I.3. Basic Concepts

I.3.1. Solar Energy

This energy is commonly harnessed through either photovoltaic or solar thermal conversion systems. These are the two main categories of solar energy applications.[4]

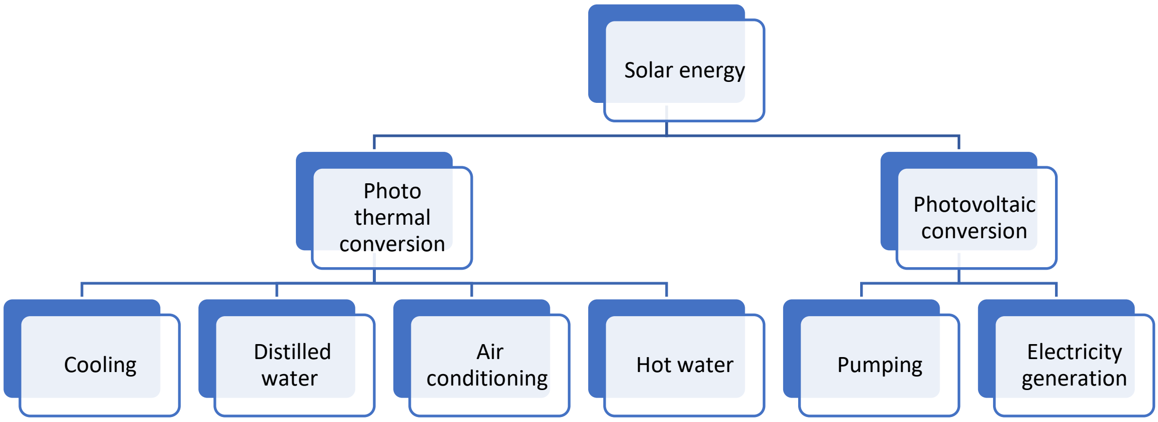


Figure I.2 Classification of Solar Energy

1. Photovoltaic solar energy

Photovoltaic (PV) solar energy derives from the direct conversion of photonic energy, including the conversion of electrical energy into electrical energy in the form of optical radiation (solar or otherwise). This is accomplished through the use of photovoltaic modules, which are composed of cells that convert energy using materials sensitive to visible light wavelengths. A photovoltaic generator (PVG) operates at a maximum power point (MPP) and exhibits a non-linear current-voltage (I–V) characteristic when multiple photovoltaic cells are connected in series or parallel. These characteristics are affected by factors such as irradiance, temperature, aging of components, and shading effects. An example of a standalone photovoltaic system is illustrated in Figure I.3.[5]

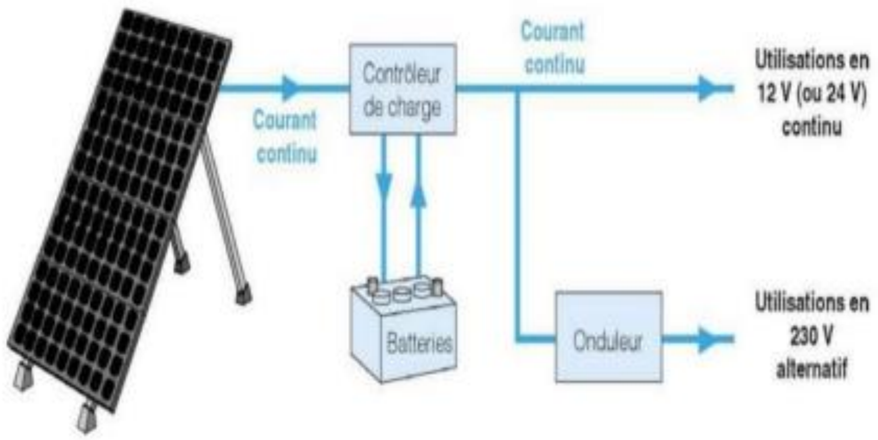


Figure I.3 Standalone photovoltaic system diagram[6]

2. Solar thermal energy:

Utilizable heat is produced from solar energy via solar thermal technology. Solar collectors gather the heat, which is subsequently transferred by a heat-transfer fluid in a hydraulic circuit that typically has one or more storage tanks for delivery at any time of day. Low-temperature applications (below 100°C) include domestic hot water systems, heating networks, and space heating. For high-temperature applications (above 100°C), solar thermal systems are used to generate steam for industrial processes and electricity generation via thermal power cycles. as shown in Figure I.1.[5]

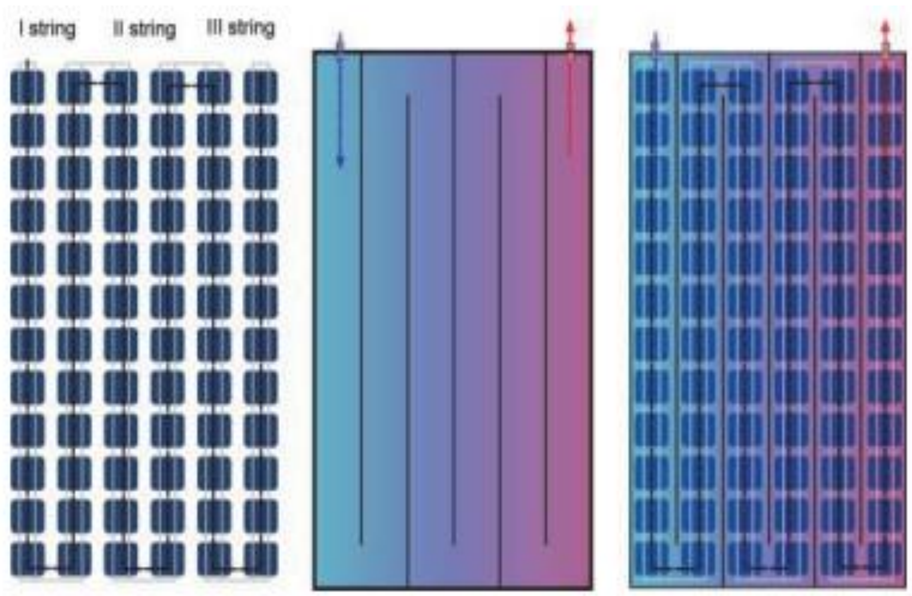


Figure I.4 PV cell matrix arrangement and water circulation in a PV/T module[7]

I.3.2. Energy from Batteries

With the increasing power load demand and considering load characteristics, more energy resources are needed given the changing generation mix. Fossil-fuel-based resources result in emissions and environmental pollution. To reduce their environmental impact and ensure sustainable energy, renewable energy resources, such as solar and wind energies, are being integrated into our energy system infrastructure. The key challenge with these renewable energy systems is their intermittent nature: they cannot continuously provide energy in a dispatchable manner. Integrating an energy storage system with renewable energy provides one possible solution to this key challenge. [8]

Battery technologies are evolving rapidly as a result of innovative materials and methodologies of battery management systems. The research focus on the SOH and remaining useful life (RUL) estimation of batteries is rapidly increasing, amounting to around 1850 research articles in 2023, as shown in Figure I.5. [8]

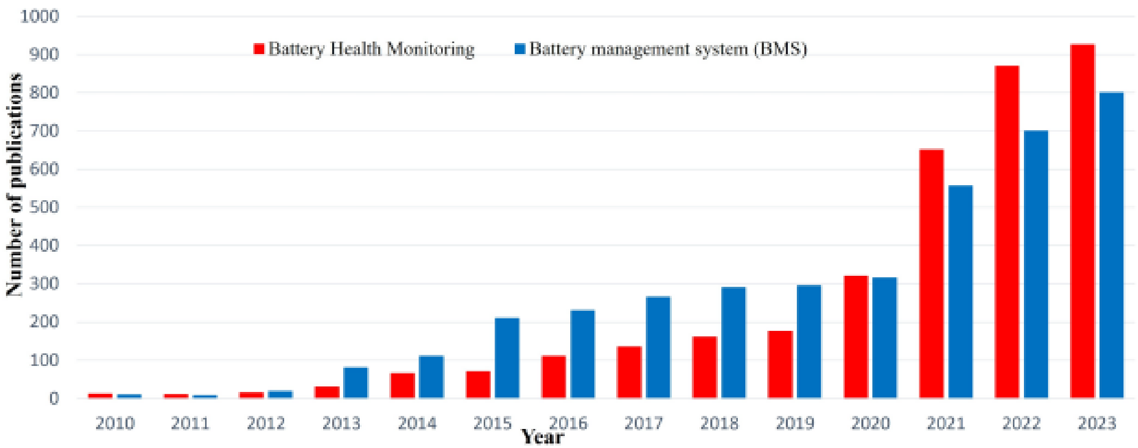


Figure I.5 Progress of research on BMS and battery health monitoring in recent years[8]

I.3.3. Arduino

Arduino is a creative platform for interactive item prototyping that consists of an electronic board with a microcontroller and a programming environment. With the aid of a wealth of online resources, this hardware and software ecosystem allows users to develop their ideas through direct experimentation without requiring any prior experience or comprehension of electronics. Since Arduino is an open-source project, everyone may find answers to their questions, thanks to the large user and design community. [9]

The Arduino platform has gained popularity among electronics enthusiasts. The Arduino software uses a simplified version of C++, which makes it easier to learn to program. It also offers a simpler environment that circumvents the functions of the microcontroller into a more accessible package. In contrast to most previous programmable circuit boards, the Arduino does not require a separate piece of hardware to load new code onto the board; instead, you can upload it using a USB cable. [10]

An Arduino board can be classified into two parts:

- Hardware

The Arduino board hardware consists of many components that combine to make it work, but we are going to discuss the main component on the board. [10]

- USB Plug: This is the first part of the Arduino because it is used to upload a program to the microcontroller and has a regulated power of 5 volts, which also powers the Arduino board .
- External Power Supply: This is only used to power the board and has a regulated voltage of 9 to 12 volts, mostly if the USB plug does not provide sufficient power for whatever you have programmed it to do .
- Reset button: This button resets the Arduino when it's pressed in case you have uploaded another command and want the Arduino to do it .
- Microcontroller: This is the device that receives and sends information or commands to the respective circuit .
- Analog Pins (O-5): These are analog input pins from AO to A5 .
- Digital I/O Pins: These are the digital input and output pins 2 and 3 .
- In-Circuit Programmer: This is another source to upload or program your program; it can also be done using TX-l, I" output, and "RX-l,O" input .
- Digital and analog Ground pins
- Power Pins: We have 3.3- and 5-volt power pins, etc.

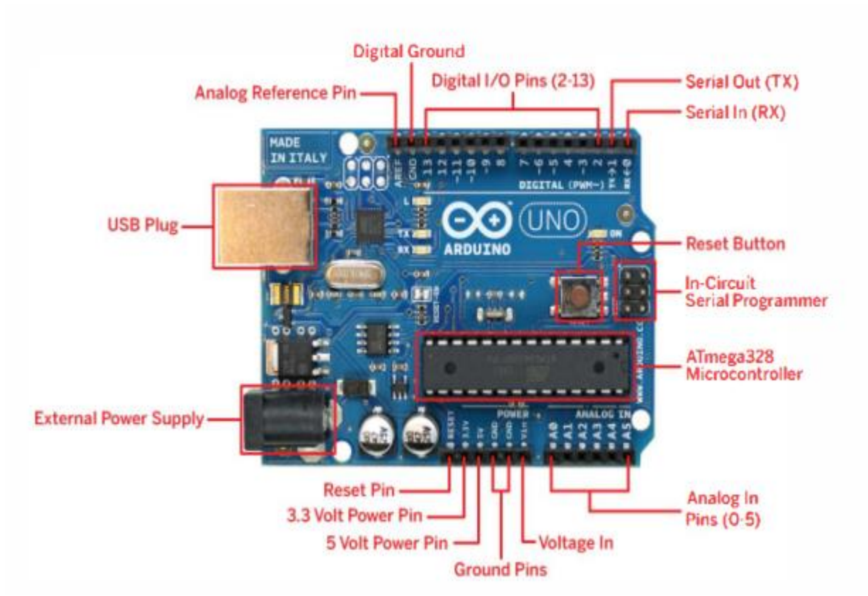


Figure I.6 Labeled Arduino Board[10]

- Software (the Arduino IDE):

The software is a set of instructions that informs the hardware of what to do and how to do it. The Arduino IDE (Integrated Development Environment) is divided into three main parts: [10]

1. **Command Area:** This is the area where you have the menu items such as File, Edit, Sketch, Tools, and Help, and icons like the Verify Icon for verification, the Upload Icon for uploading your program, New, Open, Save, and Serial Monitor used for sending and receiving data between the Arduino and the IDE.

Figure I.7 Labeled IDE[10]

2. **Text Area:** This is where you write your code, which uses a simplified version of the C++ programming language that makes writing your program easier, also called a sketch. When writing your code, there are mainly two essential parts:
    - The setup function: Before the setup, you need to initialize the variables you intend to use and assign them. Then, the setup routine begins.
    - This is where you set the initial condition of your variables and run preliminary code only once. Here is an example of how it should be written.

```
void setup() {
This where you write
your code which will run once.

}
```

    - Loop routine: This is the loop that runs or executes your main code over and over again. Here is an example.

```
void loop(){
This is where your main code is
 written, to run repeatedly.


}
```

3. **Message Window Area:** This shows messages from the IDE in the black area, mostly on verification of your code.

- **Applications:**

There are many different uses for the Arduino board. These consist of[9]

- **Controlling household appliances:** utilizing monitoring tools to give residents of a home a cozy and safe atmosphere. For example, flame detectors, gas detectors, etc .
- **Give a robot intelligence by programming it to perform intelligent tasks,** such as avoiding obstacles or moving automatically according to an Arduino board .
- **Create light shows:** command and control a light show system .
- **Using a port to disconnect a computer and exchange data** allows the computer to connect to an electronic board and other sensors. Control a mobile device with a remote

I.4. Overview of backup power systems

I.4.1. Backup power systems

Backup power systems are designed to provide reliable energy while minimizing environmental impact. These systems typically leverage renewable energy sources, energy storage solutions, and advanced technologies to create a more sustainable approach to backup power. Key components of sustainable backup power systems include:[11]

Renewable Energy Sources: Solar, wind, and other renewable energy sources provide clean power without the harmful emissions associated with fossil fuels. Solar panels, for instance, can be installed on rooftops or other available spaces to generate electricity during outages.

Energy Storage: Batteries and other energy storage technologies play a crucial role in sustainable backup power systems by storing energy generated from renewable sources for use when needed. Lithium-ion batteries are currently the most common, but emerging technologies such as solid-state and flow batteries offer promising alternatives.

Smart Inverters and Control Systems: Advanced inverters and control systems help manage the flow of electricity from renewable sources and storage devices, ensuring a seamless transition between grid power and backup power during an outage. These systems can also optimize energy use, reducing overall consumption and costs.

Microgrids: Microgrids are localized energy systems that can operate independently of the main grid. By integrating renewable energy sources and storage, microgrids provide a resilient and sustainable backup power solution for communities, businesses, and critical infrastructure

I.4.2. Practical Applications

Backup power systems based on renewable energy have seen widespread application across various sectors, particularly in areas with unreliable grid access or where energy autonomy is prioritized. In rural and agricultural settings—such as isolated farms—these systems provide a sustainable solution for ensuring power continuity for essential operations like irrigation, refrigeration, lighting, and control systems.

In recent years, photovoltaic (PV) systems combined with batteries and smart controllers (Arduino) have been successfully implemented to provide off-grid or hybrid energy setups.

These solutions offer significant advantages, including low maintenance, reduced operational costs, and environmental friendliness. The integration of smart control systems allows for automated energy source switching based on real-time data, maximizing the use of solar power and preserving battery life.

Moreover, such systems are increasingly adopted in critical facilities like hospitals, telecommunications stations, and educational institutions, where power outages can disrupt vital services. In urban settings, hybrid backup systems are used to reduce dependency on the grid and manage peak loads efficiently, especially with the integration of home automation and energy management platforms.

The case study presented in this work—focused on a model farm in southern Algeria—illustrates a practical and scalable implementation of a hybrid backup system using solar energy and an Arduino-based smart controller, tailored to the specific needs of a remote agricultural environment.

I.5. Objectives and Challenges

I.5.1. Research Objectives

Designing and implementing a smart hybrid energy management system that can intelligently transition between the electrical grid and solar photovoltaic (PV) systems to maintain a steady supply of electricity is the primary goal of this research. The system is intended for small, isolated infrastructures, such as farms, where dependable electrical supply is frequently scarce or erratic. Among the goals are

- creating a system that can keep an eye on the grid's and PV's voltage and current levels.
- putting in place an automatic switching controller based on Arduino.
- including sensors for real-time monitoring, such as voltage, current, and LDR sensors.
- System data displayed on an LCD.
- boosting the use of renewable energy sources by giving priority to solar energy where technical and environmental circumstances permit.
- controlling the allocation of loads during periods of high demand and poor battery life.

I.5.2. Technical Challenges

Among the technological difficulties encountered during the system's development were

- Ensuring precise and trustworthy voltage and current measurements from analog sensors.
- To prevent overlap or short circuits between the two power sources, the switching mechanism should be synchronized.
- Developing a logic that determines the best source by taking into account a number of variables, such as grid availability, battery level, and light intensity.
- Combining several parts (relays, sensors, LCD, Arduino Uno) into the microcontroller's constrained memory and input/output capabilities.
- To guarantee efficiency, the control system's power consumption should be kept to a minimum.
- Ensuring system stability in the face of unforeseen circumstances, such as power surges or sensor noise, and real-world volatility.

I.6. Literature Review

I.6.1. Previous Studies

Numerous scholarly and experimental investigations have focused on the incorporation of Arduino-based control systems in hybrid power generation. Among the most pertinent research:

[Energy Flow Control with Using Arduino Microcontroller in Off Grid Hybrid Power Generation System Including Different Solar Panels and Fuel Cell]

This study included a practice for efficient and effective energy use when control algorithms related to energy flow of a hybrid energy generation system consisting of different types of solar panels (monocrystalline, polycrystalline, and thin film) and fuel cells were performed. An Arduino microcontroller–based control system was designed in order to use the energy generated efficiently and effectively in hybrid power-generating systems, which consist of solar panels, battery packs, fuel cells, and direct current and alternating current loads. Routing of energy was performed by relays, and processes such as monitoring and saving data belonging to the energy-generating system and manual control of the relays optionally were performed via a LabVIEW program on the computer. The electrical energy produced by each solar panel, the energy demand of the load, and the charge–discharge conditions of the batteries were monitored through the control system designed for energy flow control. The data were analyzed, and the performances of these three control algorithms were compared. It was determined which of these three different control algorithms had the most effective and efficient energy usage. [12]

Figure I.8 Installation of monocrystalline, polycrystalline film solar panels in the hybrid energy generation system[12]

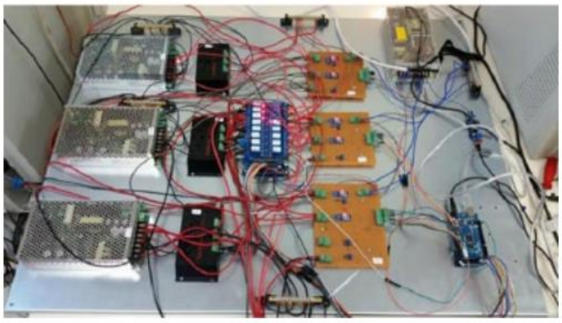


Figure I.9 Installed energy flow control system[12]

This work is particularly relevant to our research, as it demonstrates the feasibility and effectiveness of using Arduino in managing source switching and optimizing energy usage in hybrid renewable energy setups, which aligns directly with the objectives of our study.

I.6.2. Used Technologies

To perform energy flow control of the hybrid energy generating system: [12]

- a microprocessor-based Arduino Mega 2560 processor board. a 16-channel relay board,
- ACS-712T-ELC-30A current sensors and voltage sensors, which were formed via voltage divider resistors, were used.
- Three sensor cards were designed individually to perform measurement of current and voltage in each of the energy-generating systems.
- Current, voltage, and power quantities of the systems were measured via these sensor cards.

I.7. Conclusion:

This chapter provided a comprehensive analysis of the theoretical and contextual foundations of the proposed smart energy management project, particularly in remote and agricultural settings. The article examined the context of renewable energy, highlighted the importance of this research in light of frequent power failures, and addressed key technical subjects such as solar energy, battery storage, and Arduino-based control systems. The study also analyzed the main applications of backup power systems, defined its objectives and challenges, and assessed relevant previous research and technologies. The foundations laid here provide the basis for the next chapter, which will focus on the detailed technical analysis and practical implementation of the proposed hybrid energy system.

Chapter II: Technical Study Proposed System

II.1. Introduction

As the need for more sustainable and efficient energy systems grows, hybrid solutions that mix several energy sources have become necessary, especially in rural or remote places. Combining solar energy with the public grid and a smart storage system is an important step toward making energy more stable and less dependent on one source.

The main topic of this chapter is the technical examination of a smart hybrid system that combines photovoltaic panels, the public electrical grid, and batteries. A control device based on an Arduino board automatically manages the system. Its goal is to make sure that priority loads always have enough power while also making operations more efficient by monitoring data in real time and making decisions based on certain technical parameters.

This chapter gives a full picture of the system's design, its electronic parts, how it works, its electrical schematics, its core programming, and the essential technical calculations and safety needs.

II.2. General System Description

II.2.1. System Concept and Main Function

The system is based on three energy sources: photovoltaic (PV) solar panels, batteries, and the public electrical grid. These sources are automatically swapped between based on their availability and performance. The Arduino microcontroller continuously monitors the voltage and current levels to enable real-time operating decisions.

II.2.2. General Block Diagram of the System

The block diagram illustrates the major components and their **interconnections:**

- Photovoltaic solar panels
- Solar charge controller
- Battery bank
- Inverter
- Arduino with sensors
- Relays for source switching
- Electrical loads (categorized as critical, secondary, and deferrable)

These elements are configured to ensure optimal and intelligent management of power sources.

This configuration is illustrated in Figure II.1, which presents the general block diagram of the proposed hybrid energy system.

II.2.3. Operating Scenarios (With/Without the Grid)

- **With the Grid:**

  The system supplies power to loads from the public grid.

  Excess solar energy is used to charge batteries or power some loads.

- **Without the Grid:**

  The system prioritizes the use of solar energy.

  If solar energy is insufficient, batteries supply power to critical loads to ensure continuity.

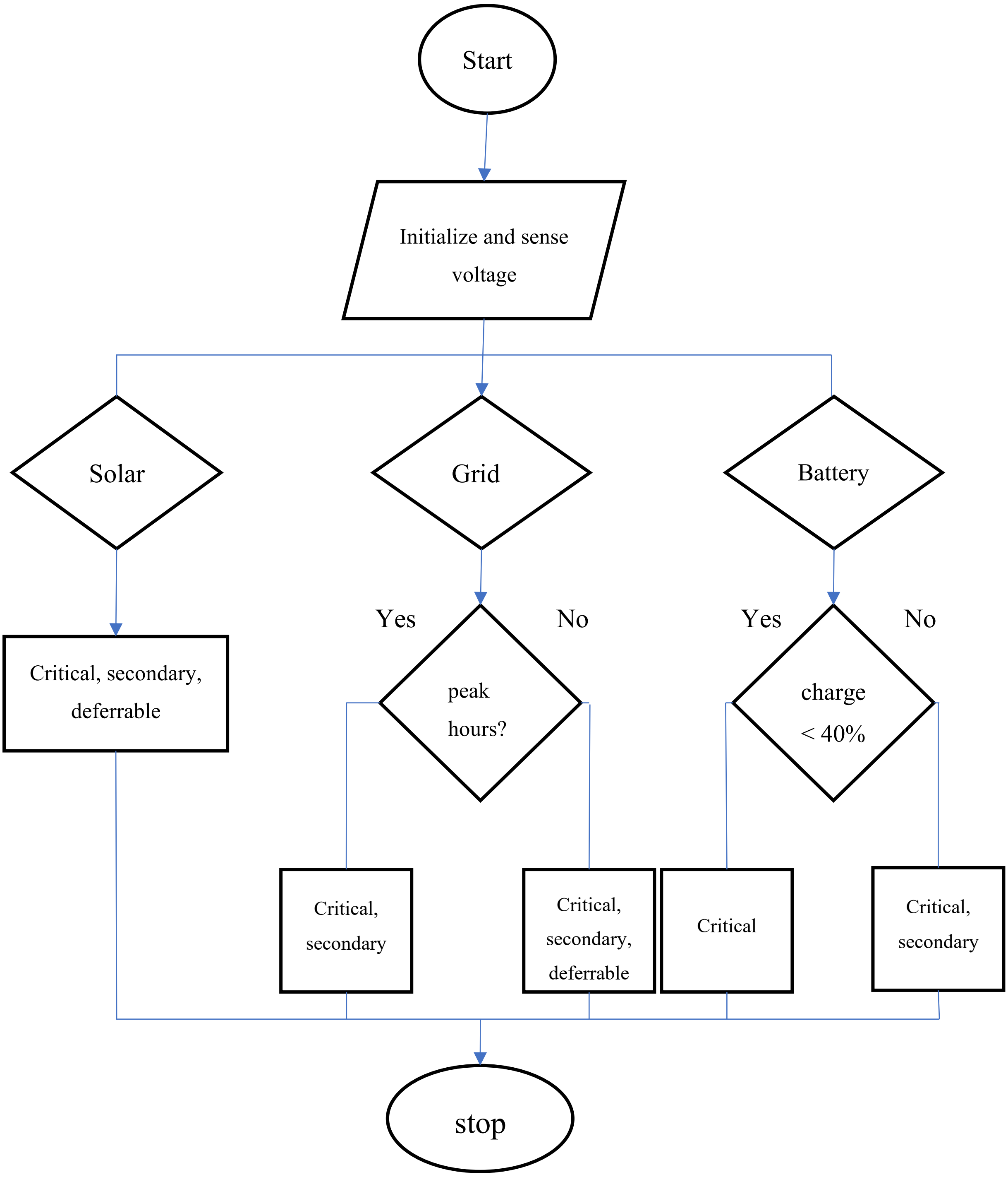


Figure II.1 Flowchart for energy source switching and load management

II.3. System Components

II.3.1. Photovoltaic Panels

These panels convert solar radiation into electrical energy (DC). The number and capacity of the panels are selected based on the energy needs of the farm.

II.3.2. Solar Charge Controller

There are different types of solar charge controllers available in the market. Depending on various concepts, the charge controllers store the energy from the solar panel to the battery backup. The most frequently used solar charge controllers are PWM-based charge controllers and MPPT-based solar charge controllers [9]. The major objective of the solar charge controllers is to control the flow of the DC energy as per the need of the battery backup. The durability of the battery will increase with the charge controller, which regulates the solar energy as per the need of the battery [10]. The working of a PWM solar charge controller depends on the current battery voltage. The PWM charge controller has an oscillating circuit whose pulse width depends on the current battery voltage. If the battery voltage is less, then the pulse width is more, and the entire input solar energy is used to store in the battery. As the battery storage voltage increases, the pulse width of the PWM reduces. Similarly, solar energy storage reduces. Once the battery backup is full, then the pulse width of a PWM just reduces to a spike. During this stage, the controller will only sense the battery voltage [11]. The major advantage of this charge controller is to improve battery life. Another popular type of solar charge controller is the MPPT type, wherein the charger will boost the input voltage during the initial stage, reducing the input current, and reduce the input voltage during the peak hour, increasing the input current. In this case, the maximum energy is utilized for the storage of the battery backup system. [13]

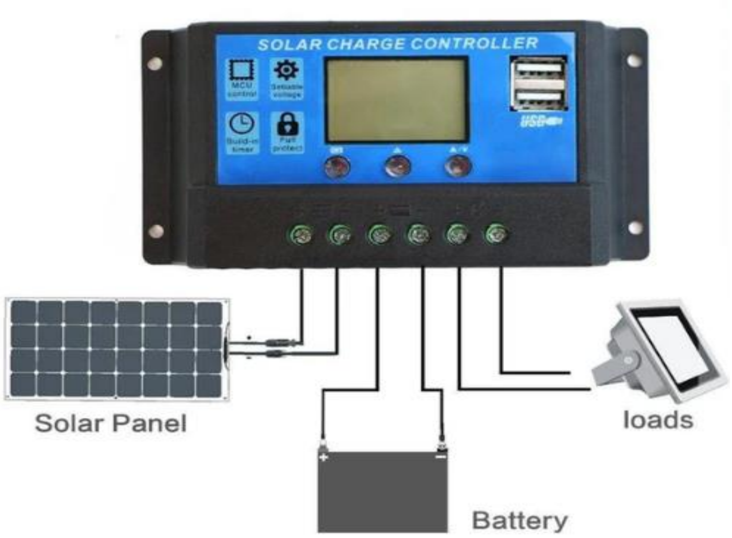


Figure II.2 solar charge controller PWM

II.3.3. Batteries

Batteries store energy for use during the night or during grid outages. Their capacity is calculated based on the expected energy consumption and backup duration.

II.3.4. Arduino (Microcontroller)

Arduino is a circuit in which its principal component is a microcontroller programmable to perform various tasks. The programming of the microcontroller used Arduino IDE, as previously mentioned. The Arduino microcontroller does not know how to perform on its own unless the instructions are written as per the demand of any study. The first step was to write the program code, compile the code on IDE with the microcontroller compiler, and upload it to the microcontroller. The programmed microcontroller used Arduino C++ code, used for the generated power from each source, in terms of voltage to maintain energy supply to the loads and to be energized at a given time. Arduino programming language was selected due to its uncomplicated programming languages as compared to others. [14]

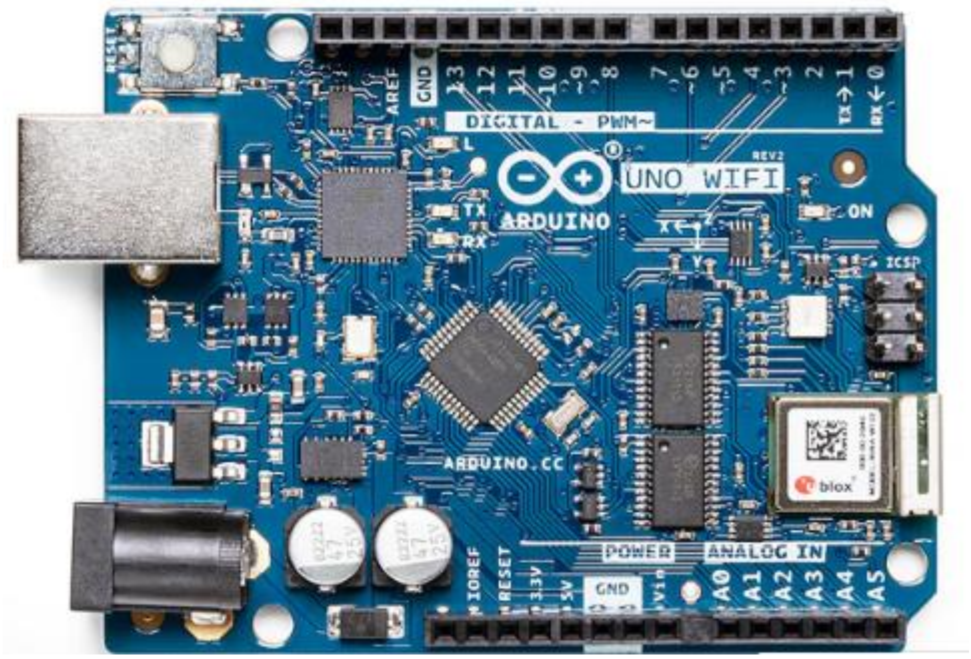


Figure II.3 Arduino UNO

II.3.5. Relays and Switching Devices

Relays are used to connect or disconnect different energy sources from various load categories based on commands issued by the Arduino.

II.3.6. Sensors

The system includes several types of sensors:

- Voltage sensors for the grid, solar panels, and batteries
- Current sensors for measuring power flow
- Light sensor (LDR) to detect sunlight intensity and aid in source selection

II.4. System Operation

II.4.1. Power Outage Detection Mechanism

The system keeps an eye power goes out, an Arduino is in charge of energy is the main source if the voltage is high enough (≥11V) and the light intensity is low enough (LDR < 500). system's voltage is 11.5V or higher, it will switch to the grid if solar power isn't available. available, it uses the batteries as long as their voltage is at least 10.5V. sequence runs automatically to make sure there is always power, even when no one is around.

II.4.2. Automatic Source Switching

- Relays that are directly controlled by the Arduino are used to manage source switching.
- Depending on the assessed conditions, the system connects the new source and disconnects the inactive one.
- Each switching event has a brief delay built in to guarantee voltage stabilization and shield delicate components from sudden changes.

II.4.3. Role of Arduino in Control

The Arduino performs the following tasks, which are essential to the system's intelligent operation:

- obtaining information from sensors for light, voltage, and current.
- Analysis of energy availability in real time.
- Relay control for dynamic energy source switching.
- Voltage, current, and active source statistics are displayed on the LCD panel.
- The Arduino code is made to react quickly to changes in the energy supply, guaranteeing smooth operation without the need for user input.

II.4.4. Power Flow in the System

Energy flow varies depending on system conditions and can be summarized as follows:

- **Normal Operation (Grid + Solar Available):** Loads are primarily powered by solar energy. The grid may be used to charge batteries or act as backup.
- **Grid Outage with Solar Available:** Loads are powered directly by solar panels. Batteries may continue charging if energy is sufficient.
- **No Grid and Low Solar Energy:** Batteries supply power to critical loads only.
- **Only Grid Available:** The grid supplies power to the loads and recharges the batteries.

This design demonstrates the system's adaptability and capacity to provide electricity continuously, especially in remote or off-grid settings where energy stability is a problem.

II.5. Electrical Schematics and Circuits

II.5.1. Arduino Pin Connections with Components:

The Arduino board acts as the central processing unit of the system and is connected to the various components as follows:

- **Analog Inputs (A0–A5):** Used to read voltage values from sensors monitoring the solar panels, grid, and batteries.
- **Digital Inputs (for Push Buttons):** Allow manual user commands such as forced switching or system reset.
- **Digital Outputs (for Relays):** Control the activation or deactivation of energy sources by switching the relays based on decision logic.
- **LCD Interface:** Displays real-time information such as voltage, current, and the currently active source.

This structured wiring enables precise monitoring and control decisions to be made dynamically.

II.5.2. Arduino Programming: General Code Structure

The control logic follows a modular software structure:

- **setup() Function:**

  Initializes all components, sets pin modes, begins communication with the display, and prepares sensors for operation.

- **loop() Function:**

  Runs continuously to read voltage and current data, analyze it, make switching decisions, and update the LCD display.

- **Periodic Data Update Logic:**

  Data is refreshed at regular intervals (e.g., every 500 ms) to ensure prompt system response to any change in source or load status.

II.6. Technical Considerations

II.6.1. Power and Energy Requirements Calculations

Finding out how much electrical power and energy is needed is a key part of designing the proposed hybrid system. This process starts with a close look at the electrical loads that are used in the area being studied. A complete table is made that includes all electrical devices, their rated power (in watts), the number of hours they are used each day, and the number of times they are used each month.

Using this information, we can figure out how much energy is used each day and each month. We also add a safety margin of 20% to 30% to make up for technical losses that happen when components aren't working as well as they should (like inverters, wiring, charge controllers, etc.). Also, you need to think about peak loads (surge loads), which are extra power that some devices, like pumps, need when they start up.

These calculations help us figure out the right battery capacity and the right number of photovoltaic panels so that the system can reliably meet energy demand in a variety of operating conditions.

II.6.2. Safety and Protection Considerations

Designing a hybrid power system requires a range of safety and protection measures to ensure both user and equipment security. Key practices include:

- **Overcurrent protection**, using appropriate circuit breakers on all major lines.
- **Reverse polarity protection**, through the use of blocking diodes, especially between panels and batteries.
- **Proper grounding** of the system to protect against lightning strikes or static discharges.

- **Smart charge controllers**, to avoid battery overcharging or deep discharging, which prolongs battery lifespan.
- **High-voltage isolation**, using enclosed distribution boxes away from user access.

These protections improve system reliability and reduce risks of electrical faults or fires, particularly in rural or agricultural settings where infrastructure may be limited.

II.7. Conclusion

Through this technical study, various aspects of the design and implementation of a smart system for managing the switching between the public grid and solar energy in a backup power setup for a model farm have been addressed.

The chapter provided an overall system description, detailed the primary components and their roles, and explained how the Arduino-based controller processes electrical data to make real-time switching decisions based on sensor inputs. Supporting electrical schematics and code structure were also discussed to illustrate the system logic.

Finally, the chapter outlined the essential technical calculations for energy sizing and emphasized critical safety measures. The findings confirm that a simple, cost-effective, and intelligent solution can ensure energy continuity in rural agricultural settings, thereby enhancing productivity and reducing dependency on the public electricity network.

Chapter III: Case Study of a Model Farm

III.1. Introduction

This chapter delineates the practical aspect of the study by detailing the development and execution of a functional prototype that emulates an intelligent energy management system within a model farm. The prototype utilizes an Arduino microcontroller to regulate power distribution among various load categories (critical, secondary, and deferrable) based on defined operational parameters, including peak hours and low battery circumstances. This chapter emphasizes the practical validation of the system's performance in a real agricultural context, allowing for an assessment of its technical efficiency and operational reliability based on real-world testing and observed energy behavior.

III.2. Presentation of the Model Farm Under Study

III.2.1. General description of the farm

Ben Sassi Farm, situated on National Road No. 56 in Hassi Ben Abdallah, Ouargla Province, encompasses an area of 220 hectares. It features a contemporary automatic drip irrigation system. The farm comprises a diverse assortment of olive trees, including international cultivars such as Arbequina, Arbosana, and Koroneiki from Spain, alongside local species like Chemlal and Sigoise.

The plantation employs a dual planting system that integrates intensive and spaced planting techniques, facilitated by an integrated fertigation station through the "GotFut" irrigation system. The farm contains a dedicated olive oil extraction and filter plant, as well as a tree nursery now in development.

Ben Sassi Farm possesses a comprehensive water infrastructure, featuring four artesian wells, each reaching a depth of 120 meters and exhibiting a flow rate of 30 liters per second. A 90,000-liter subterranean water tank is equipped with a 20-horsepower pump. The farm depends on a direct electrical connection devoid of battery storage technologies, exemplifying sustainability and efficiency in contemporary agriculture.

III.2.2. Energy consumption analysis:

III.2.2.1. Total energy consumed

To determine the total energy consumption of the model farm during a specific period, two primary data sources were used:

- A theoretical estimation based on the specifications and usage time of electrical devices.
- Official electricity bills provided by the utility company.

a) Theoretical Energy Consumption Estimation

A detailed table was made that showed all of the electrical devices on the farm, such as pumps, lighting systems, control equipment, and more. The table shows the rated power of each device (in watts), how many hours a day it runs, and how many days a month it is used. Using these numbers, we figured out how much energy each device used each month and added them all up to get an estimate of the total usage. as shown in Table III-1.

This table is a basic guide for figuring out how big the energy system needs to be. It helps figure out how many solar panels and batteries are needed to make sure that essential loads always get power.

Table III-1 Electrical consumption table of the farm

Electrical Element	Quantity	Power (kW)	Daily Operating Hours	Daily Energy Consumption (kWh)	Additional Notes
Water Pump	4	14.9	12	715.2	Main irrigation system
LED Light	24	0.05	8	9.6	Efficient lighting for internal/external areas
Mixer	1	1.5	2	3	For mixing feed or materials
Oil Presser	1	10	3	30	Main oil extraction unit
Lamp (Incandescent)	5	0.06	6	1.8	Older lighting system
Air Conditioner	2	2	8	32	Cooling offices and processing areas

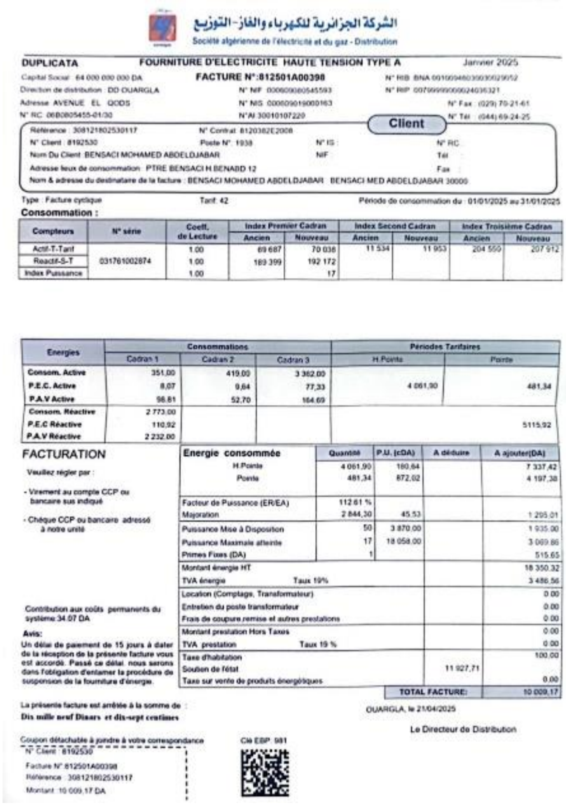
TV	1	0.1	5	0.5	For control room or lounge
Transformer	1	1	24	24	Voltage conversion and distribution
Projector	1	0.2	4	0.8	Used in meetings or presentations
Microwave	1	1.2	0.5	0.6	Staff kitchen
Oven	1	2.5	1	2.5	Kitchen or processing use
Heater	1	1.5	4	6	For winter heating needs
Oil Press Motor	1	15	3	45	Drives the oil pressing mechanism
Oil Filtering Unit	1	3	2	6	Filters oil after pressing
Oil Bottling Machine	1	2	4	8	Packaging finished oil products
Control Panel (PLC)	1	0.5	24	12	Automation and monitoring
Ventilation Fan	2	0.2	12	4.8	Cooling production areas
Olive Washer	1	2	3	6	Cleans olives before processing
Conveyor Belts	3	0.75	3	6.75	Transport olives through stages
Olive Crusher (Mill)	1	7.5	3	22.5	Crushes olives into paste
Malaxer (Mixer)	1	4	3	12	Mixes olive paste

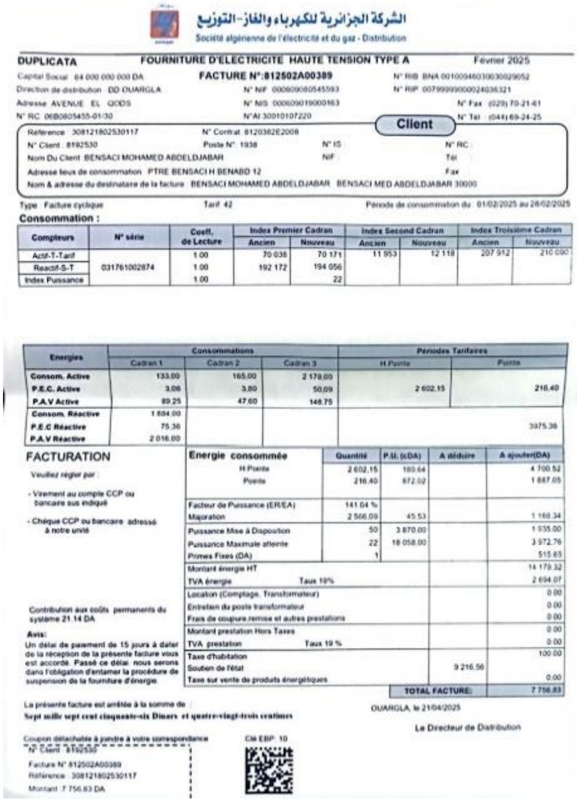
Decanter (Centrifuge)	1	12	3	36	Separates oil, water, and solids
Vertical Separator	1	3	2	6	Final purification of olive oil
Filtration Unit	1	1.5	2	3	Removes remaining impurities
Bottling Machine	1	2	4	8	Bottles and caps the oil
PLC Control Panel	1	0.5	24	12	Controls the entire pressing process
Internal Lighting (LED)	10	0.05	8	4	Lighting inside pressing area
Sum	**1018.05 kWh**				

The theoretical table gives a simple but useful look at the expected monthly energy needs. It makes it easier to find equipment that uses a lot of power and shows possible ways to improve load scheduling. But it is still an approximation because it assumes that the system will always work the same way and doesn't take into account changes in the environment or the way it works. So, this analysis needs to be backed up with data from the real world.

b) Electricity Bills

We got a few official electricity bills for the farm over the course of several months so that we could compare the estimated data with the actual energy use. The total cost, total energy use in kilowatt-hours (kWh), meter reading dates, and number of billing days are all important pieces of information on each bill. as shown in Figure III-1.





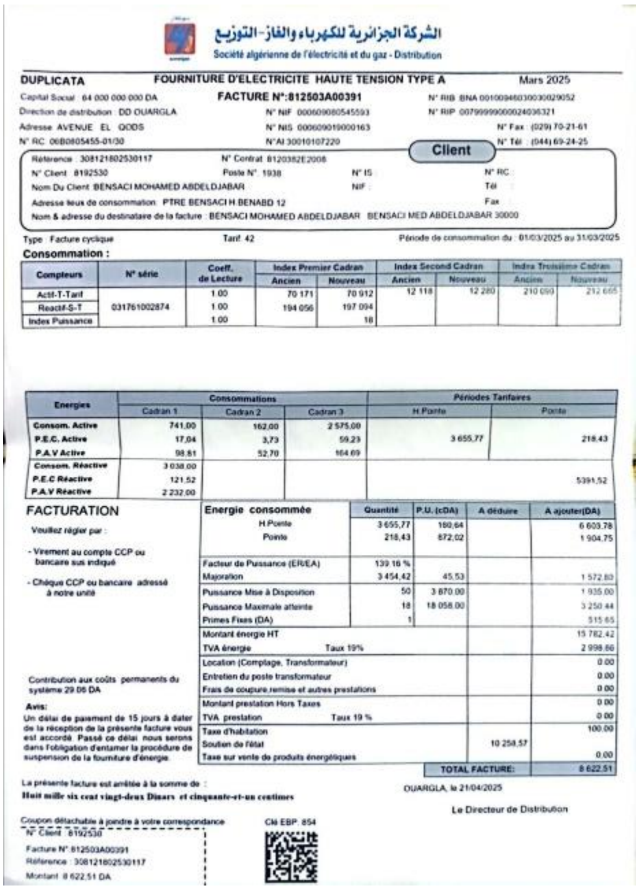


Figure III.1 Samples of official electricity bills used to analyze actual energy consumption for the months of January, February, and March..

The electricity bills reflect the actual energy drawn from the grid during the observed periods. These values account for all on-site consumption, including any additional or occasional equipment that may not be considered in the theoretical estimation.

Notably, fluctuations between months are evident, often correlating with agricultural activity cycles, seasonal changes in irrigation demand, and other operational factors. The bills also include energy losses within the system, such as transmission inefficiencies, which are typically not included in the theoretical model.

c) Comparative Discussion:

When comparing the values from the theoretical estimation with the actual consumption shown in the bills, some discrepancies are observed. These differences may be attributed to several factors:

- **Variations in operational behavior:** Devices may not run as consistently as assumed in the estimation.
- **Seasonal activity differences:** Power needs can shift significantly depending on agricultural tasks and climate conditions.
- **Internal losses:** Real-world systems experience energy losses due to cable resistance, inefficient devices, or unmonitored consumption.
- **Omission of secondary loads:** Some low-power or infrequent-use devices may have been overlooked in the theoretical model.

Despite these discrepancies, combining both sources of data provides a more comprehensive understanding of the energy profile. It allows for a balanced approach when designing a hybrid energy system that is both efficient and well-suited to the farm's actual needs.

III.2.2.2. Consumption breakdown by equipment or activity

Based on the load classification established in previous chapters—dividing loads into critical loads (ventilation systems, computers, control units), medium-priority loads (lighting, small pumps), and deferrable loads (cleaning equipment, auxiliary devices)—we can provide a scientific analysis of energy consumption distribution within the farm.

The electricity bill reveals that a significant portion of energy is consumed during peak hours (heure de pointe), indicating that most equipment operates during daytime periods. This aligns with the operating schedule of heavy and medium loads, such as

- Large water pumps and irrigation systems, which usually operate during fixed daylight hours, are major contributors to total consumption. These fall under deferrable or schedulable loads.
- Cold storage units (chambre froide), which operate continuously to preserve agricultural products, are categorized as critical loads with top priority.
- Lighting and secondary equipment are considered deferrable loads depending on necessity and represent a relatively smaller share of consumption.
- Moreover, the presence of high reactive energy consumption (2,773 kVARh) suggests intensive use of inductive loads, such as irrigation pumps or compressors, without power factor correction systems. This lowers the power factor, resulting in financial penalties (noted as "Majoration" in the bill), highlighting the importance of timing and load management.

From this analysis, we can conclude:

- A substantial share of energy is consumed by loads that are manageable and schedulable.
- There is a real opportunity to reduce costs through time-based control of non-essential loads and by implementing reactive power compensation using capacitors.

III.2.2.3. Energy Demand Pattern

The energy demand at Ben Sassi Olive Farm exhibits a non-uniform distribution throughout the day, predominantly influenced by agricultural activities and seasonal fluctuations. Peak energy consumption occurs during daylight hours, especially from 8:00 AM to 4:00 PM, when equipment such as water pumps, drip irrigation systems, sorting machines, and packaging units are actively used.

During irrigation seasons (spring and early summer), energy demand significantly escalates due to the operation of high-capacity electric pumps. Evening consumption is negligible, primarily owing to insufficient lighting and sporadic utilization of refrigeration units. The farm demonstrates a single-peak daily load profile, characterized by a demand surge at midday, followed by a gradual decline toward evening, with minimal usage during the night.

III.3. Geographical Description of the Site

III.3.1. Geographic location

Ben Sassi Farm is located in the commune of Hassi Ben Abdellah, within the Sidi Khouiled District of Ouargla Province, approximately 20 kilometers from the provincial capital, Ouargla. Its geographical coordinates are 32.0258° N latitude and 5.4687° E longitude. The elevation of the area ranges from 100 to 256 meters above sea level, with an average of approximately 159 meters, reflecting a generally flat to slightly undulating terrain.

The farm lies within the low Saharan plateaus, characterized by sandy to light clay soils, which provide favorable conditions for the installation of photovoltaic solar systems. Additionally, the site benefits from easy access via National Road No. 56, which connects Ouargla to Hassi Ben Abdellah, facilitating installation, maintenance, and regular monitoring of the energy system.

III.3.2. Climatic conditions

The Ouargla region benefits from highly favorable climatic conditions for solar energy exploitation. It records an average annual solar irradiance of approximately 2263 kWh/m², along with more than 3900 hours of sunshine per year, making it one of the sunniest areas in Algeria. The average daily solar irradiance ranges between 5.5 and 7.8 kWh/m², peaking in June, ensuring abundant solar energy throughout the year.

The average annual temperature is around 24.4°C, with extremes reaching up to 50°C on July 30, 2023, and dropping to -1.4°C on January 23 of the same year. The region experiences significant daily and seasonal thermal variation—often exceeding 30°C—which can affect the performance and lifespan of electrical equipment and batteries, and must be taken into account during system design.

Regarding precipitation, the area is characterized by extremely arid conditions, with an average annual rainfall of just 2.27 mm. The relative humidity remains medium to low, averaging 28.9%, which helps reduce corrosion risks on electrical components. In addition, the region experiences an average wind speed of 11 km/h, with stronger winds typically occurring between March and July. It is also known for hot and dry "Sirocco" winds, especially from February to April, which necessitate regular cleaning and maintenance of photovoltaic panels to maintain optimal performance.

III.4. Simulation-Based Experiment

III.4.1. Simulation Steps

At this step, the prototype of the system was developed utilizing Fritzing, a proficient tool for visual circuit design and documentation. The software was utilized to precisely organize the electrical wiring, particularly given the numerous components involved in this project, including

- **Solar Panel:** Generates electrical power by converting sunlight into direct current (DC).
- **Solar Charge Controller:** Regulates the flow of energy from the solar panel to the battery and the system. It protects the battery from overcharging or deep discharge.
- **Battery (12V Li-ion):** Stores solar energy and acts as a backup power source when solar input is unavailable.
- **Arduino Uno:** Serves as the main controller, processing voltage readings and making switching decisions based on programmed logic.
- **Voltage Sensors:** Monitor the voltage of the grid, solar panel, and battery in real time.
- **Relay Module:** Acts as electronic switches to connect or disconnect different loads depending on the available power source.
- **Fans and lamps represent** different types of loads (critical, medium, and non-critical) in the simulation.
- **Push Buttons:** Simulate specific scenarios such as peak hours or low battery warnings, feeding digital inputs to the system logic for behavior adjustments.

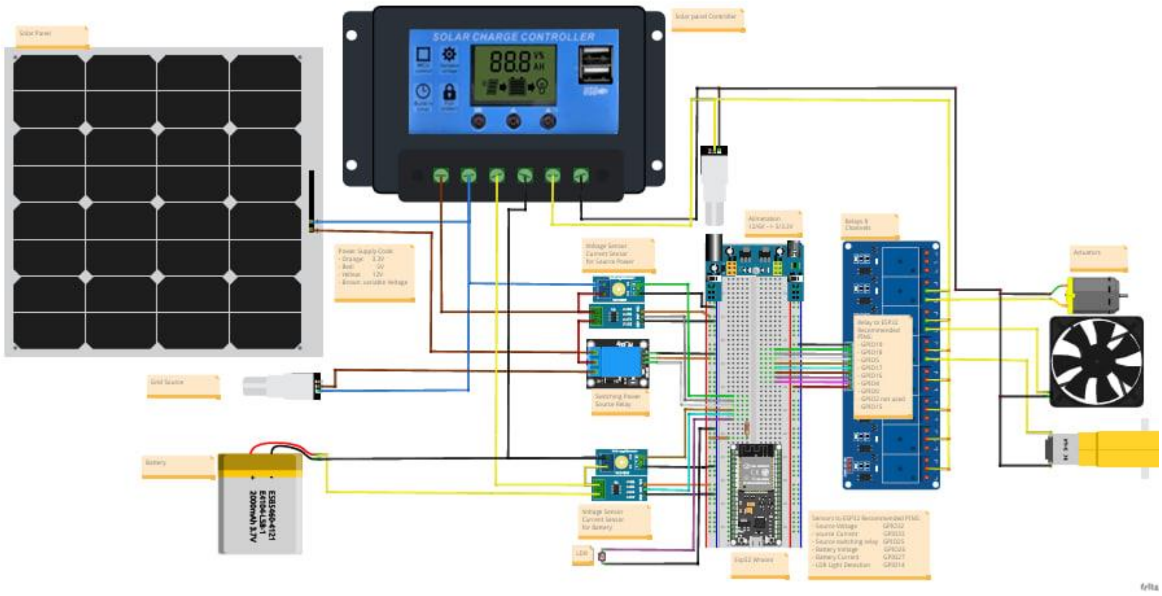


Figure III.2 Prototype Simulation of the Hybrid Power Management System Including Load Control and Push Button Inputs

This prototype facilitated a distinct representation of the system architecture prior to physical execution. It aided in verifying the wiring logic and assuring compatibility with the control code, hence reducing potential errors and streamlining the actual installation during the field testing phase.

III.4.2. Results Display and Analysis

Several scenarios were tested through the simulation:

- When solar power is available with sufficient voltage, it directly powers the loads and charges the battery if possible.
- When solar input is weak or unavailable, the system switches automatically to battery power.
- If the battery voltage drops below a critical threshold (e.g., 11.5 V), the system switches to the utility grid.
- In emergency situations (e.g., no solar power, low battery, and no grid), the system disconnects medium and non-critical loads automatically, maintaining only critical loads.
- The schematic diagram shows the detailed wiring between components, and the simulation confirms that the system responds correctly to voltage variations, performing automatic switching based on predefined logic.

III.4.3. Evaluation of the Virtual Model

This simulation model represents a key development phase, allowing

- Testing of the control logic without risk to actual hardware
- Identification of wiring or programming errors
- Preparation of a flexible testing environment

The use of Arduino Uno provided a reliable platform for reading sensor data and controlling relays. Additionally, the design remains open for future integration of display interfaces or wireless communication modules such as Bluetooth or GSM.

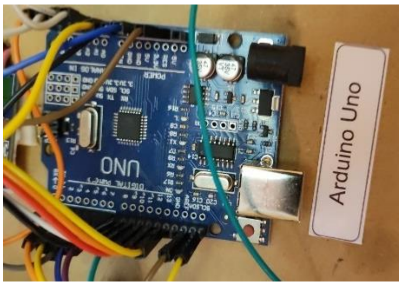
III.5. Field Implementation and Testing

III.5.1. Development and Installation of the Prototype

A miniature prototype was developed and constructed to emulate the functionality of the energy management switching system on the farm. This prototype sought to evaluate the algorithm implemented on the Arduino controller and assess system performance prior to comprehensive deployment.

The implementation stages included:

- Setting up a breadboard integrated with the core control components.
- Connecting the Arduino controller to the system components, which include
- Voltage and current sensors to monitor the performance of energy sources.
- LCD display to show the system status (active source, load state, etc.).
- Relays to control turning loads on and off according to their priority.
- Push buttons to simulate conditions like peak hours or battery low voltage.



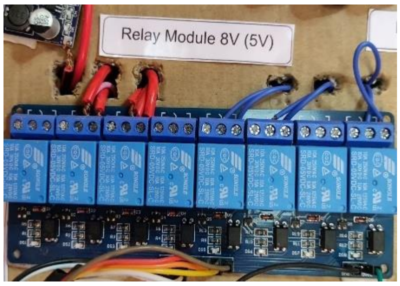


Figure III.3 Instruments used in the experimental model

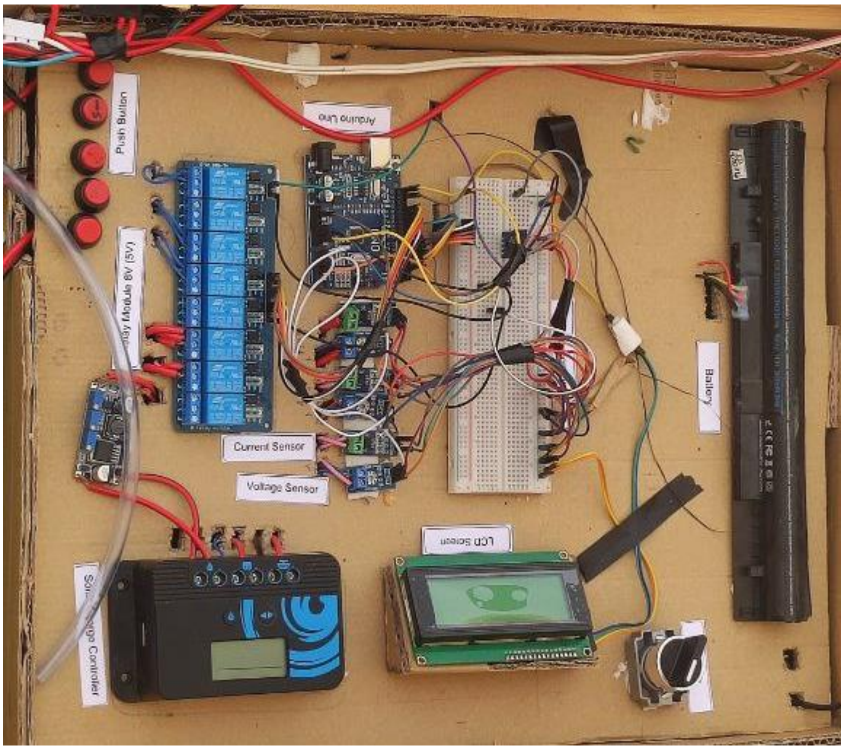


Figure III.4 The control section of the practical setup

- Solar charge controller to regulate energy flow from the solar panels to the battery and protect it.
- A battery to store solar energy and ensure load continuity during the absence of sun or grid outages.

Programming the algorithm to manage switching between

- Solar energy.
- Public electricity grid.
- Battery (when available).

Organizing loads into three categories:

- Critical loads (must always remain powered).
- Secondary loads (powered when sufficient energy is available).
- Deferrable loads (disconnected during emergencies or peak hours).

Photos of the hands-on prototype:

III.5.2. Measuring Prototype Performance

The prototype was tested in a controlled workshop environment with several simulated scenarios, such as

- Operating the system using solar energy only.
- Simulating peak hours using a dedicated button.
- Simulating low battery voltage.
- Testing automatic switching to the grid during solar absence and battery discharge.
- Testing load control according to priority levels.

Results:

- The system responded effectively to the programmed conditions.
- Switching between sources was smooth and automatic.
- Loads operated based on their defined priorities.
- The LCD displayed all changes and readings clearly.
- Minor improvements were made to enhance timing precision and reduce relay bounce.

III.5.3. Challenges and Field Observations

- Sensor calibration required more precision during voltage simulations.
- Relay components produced noticeable heat during prolonged use, requiring better ventilation.
- Structural reinforcement of the prototype was necessary for extended testing periods.
- The solar charge controller performed well in protecting the battery and managing current flow.
- Overall, the prototype successfully validated the algorithm with room for optimizing response time in some edge cases like sudden peaks.

III.6. Final Analysis and Benefits

III.6.1. Technical Benefits

- **Enhanced Power Supply Continuity:** Thanks to the intelligent switching system between the grid, solar energy, and batteries, a continuous power supply was ensured, particularly during outages or low-voltage periods. This is crucial for operating critical loads such as water pumps or cooling systems on the farm.
- **Improved Resource Utilization Efficiency:** The system uses simple but effective algorithms (e.g., voltage comparison) to determine the most appropriate energy

source at any given moment. This reduces energy losses and maximizes the efficient use of solar power and battery storage.

- **Accurate Load Management:** Loads are classified into critical, medium, and non-essential categories. This allows the system to selectively power or disconnect them based on priority and energy availability, helping to prevent battery depletion in critical situations and maintaining consumption balance.
- **Flexibility and Easy Scalability:** By relying on the Arduino platform, the system is easily upgradable and adaptable to changes in energy consumption or the integration of new features, such as weather monitoring or wireless control.

III.6.2. Future Improvements and Expansion Suggestions

- **Integration of Remote Monitoring Modules:**

Modules like GSM or WiFi can be incorporated to facilitate remote monitoring of the system's status (voltage levels, battery condition, load status). Alerts can be established in the event of malfunctions or energy deficits

- **Implementation of MPPT Algorithms:**
  Maximum Power Point Tracking (MPPT) algorithms can optimize the extraction of solar energy, especially under variable weather conditions. This could be achieved using external MPPT controllers or by developing a dedicated software algorithm.
- **PCB-Based System Integration:**
  Instead of using a breadboard setup, designing a printed circuit board (PCB) will increase the reliability of the system, reduce connection errors, and make the system more robust in the farm's physical environment.
- **Incorporating Additional Energy Sources:**
  Additional sources such as a diesel generator or a wind turbine can be integrated as backup solutions during low solar radiation seasons or extreme energy demands.
- **Integration with Weather and Irrigation Data:**
  By adding sensors for temperature, humidity, and water level, the system can evolve to support smart agricultural decisions—beyond energy management—to improve irrigation efficiency and crop productivity.
- **Implementation of Data Logging and Analytics:**

Recording daily system performance and analyzing long-term trends will help in fine-tuning the energy management logic and making data-driven decisions for future enhancements.

III.7. Conclusion

This practical chapter provided a comprehensive study of energy consumption in a model farm by collecting and analyzing data using multiple tools, including Excel for accurate energy consumption profiling.

A functional prototype for intelligent power source switching was also developed using platforms like Arduino, allowing realistic system simulation and performance evaluation under different operating conditions.

The experiment demonstrated that smart energy management solutions are efficient and well-suited, especially for rural and agricultural areas with limited resources.

By combining software-based analysis, field experimentation, and real-world modeling, this chapter represents a key step toward developing scalable hybrid systems with high technical and economic viability.

General conclusion

General conclusion

This thesis aimed to contribute to the development of smart technical solutions for efficient energy management, especially in rural and agricultural areas that often suffer from weak or unstable electricity supply. By studying and designing a hybrid system that integrates solar energy, the public grid, and battery storage, we were able to implement a practical model capable of ensuring continuous power supply to priority loads while maximizing the use of available solar energy.

The system relied on an Arduino board as the main control unit, integrating various sensors and electronic components, which enabled real-time monitoring and automatic switching between sources based on availability and efficiency. The study covered various theoretical and technical aspects, from the fundamentals of solar energy through technical and programming analysis to field testing at the Ben Sassi model farm in the Wilaya of Ouargla.

The results showed that such systems can serve as practical and economical alternatives in areas where full reliance on the public grid is difficult. They also help improve energy management and enhance energy autonomy.

In conclusion, we emphasize the importance of integrating renewable energies with smart monitoring and control systems. We recommend continuing research and development in this field, particularly through the adoption of more advanced technologies such as artificial intelligence and the optimization of decision-making algorithms to further enhance system efficiency in the future.

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Annex

The code used to control our system using the **ARDUINO IDE** program:

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27, 20, 4);  // LCD 20x4
const int Solar_Sen_Pin = A0;
const int Grid_Sen_Pin = A1;
const int Battery_Sen_Pin = A2;
const int LDR_Pin = A3;
const int Grid_Current_Pin = 3;
const int Relay_Solar = 8;
const int Relay_Grid = 9;
const int Relay_Critique = 11;
const int Relay_Secondary = 12;
const int Relay_Defamable = 13;
const int Button_PeakHours = 6;
const int Button_Battery40 = 7;
const int Button_Critique = 2;
const int Button_Secondary = 4;
const int Button_Defamable = 10;
const int Led_LDR = 5;
const float VOLTAGE_FACTOR = 25.0 / 1023.0;
const float CURRENT_FACTOR = 5.0 / 1023.0;
float Solar_Volts, Grid_Volts, Battery_Volts;
float Grid_Current;
int ldrValue = 0;
bool isPeakHours = false;
bool isBatteryLow = false;
bool stateCritique = false;
bool stateSecondary = false;
bool stateDefamable = false;
bool lastStateCritique = HIGH;
bool lastStateSecondary = HIGH;
bool lastStateDefamable = HIGH;
String currentSource = "NONE";
void setup() {
  Serial.begin(9600);
  lcd.init();
  lcd.backlight();
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print(" SMART HYBRID SYS ");
  delay(2000);
  lcd.clear();
  pinMode(Solar_Sen_Pin, INPUT);
  pinMode(Grid_Sen_Pin, INPUT);
```

```
  pinMode(Battery_Sen_Pin, INPUT);
  pinMode(LDR_Pin, INPUT);
  pinMode(Grid_Current_Pin, INPUT);
  pinMode(Relay_Solar, OUTPUT);
  pinMode(Relay_Grid, OUTPUT);
  pinMode(Relay_Critique, OUTPUT);
  pinMode(Relay_Secondary, OUTPUT);
  pinMode(Relay_Defamable, OUTPUT);
  pinMode(Button_PeakHours, INPUT_PULLUP);
  pinMode(Button_Battery40, INPUT_PULLUP);
  pinMode(Button_Critique, INPUT_PULLUP);
  pinMode(Button_Secondary, INPUT_PULLUP);
  pinMode(Button_Defamable, INPUT_PULLUP);
  pinMode(Led_LDR, OUTPUT);
  digitalWrite(Relay_Solar, HIGH);
  digitalWrite(Relay_Grid, HIGH);
  digitalWrite(Relay_Critique, HIGH);
  digitalWrite(Relay_Secondary, HIGH);
  digitalWrite(Relay_Defamable, HIGH);
  digitalWrite(Led_LDR, LOW);
}
void loop() {
  Solar_Volts = analogRead(Solar_Sen_Pin) * VOLTAGE_FACTOR;
  Grid_Volts = analogRead(Grid_Sen_Pin) * VOLTAGE_FACTOR;
  Battery_Volts = analogRead(Battery_Sen_Pin) * VOLTAGE_FACTOR;
  Grid_Current = analogRead(Grid_Current_Pin) * CURRENT_FACTOR;
  ldrValue = analogRead(LDR_Pin);
  digitalWrite(Led_LDR, ldrValue < 500 ? HIGH : LOW);
  isPeakHours = !digitalRead(Button_PeakHours);
  isBatteryLow = !digitalRead(Button_Battery40);
  lcd.setCursor(0, 0);
  lcd.print("S:"); lcd.print(Solar_Volts, 1); lcd.print("V ");
  lcd.print("G:"); lcd.print(Grid_Volts, 1); lcd.print("V ");
  lcd.setCursor(0, 1);
  lcd.print("B:"); lcd.print(Battery_Volts, 1); lcd.print("V ");
  lcd.print(" LDR:"); lcd.print(ldrValue);
  String newSource = "NONE";
  if (Grid_Volts >= 11.5) {
    if (ldrValue < 500 && Solar_Volts >= 11) {
      newSource = "SOLAR";
    } else {
      newSource = "GRID";
    }
  } else {
    if (ldrValue < 500 && Solar_Volts >= 11) {
      newSource = "SOLAR";
    } else {
      newSource = "BATTERY";
    }
```

```
  }
  if (newSource != currentSource) {
    digitalWrite(Relay_Solar, HIGH);
    digitalWrite(Relay_Grid, HIGH);
    delay(1000);
    if (newSource == "SOLAR") {
      digitalWrite(Relay_Solar, LOW);
      lcd.setCursor(0, 2); lcd.print("MODE: PV OVERRIDE     ");
    } else if (newSource == "GRID") {
      digitalWrite(Relay_Grid, LOW);
      lcd.setCursor(0, 2); lcd.print("MODE: GRID            ");
    } else if (newSource == "BATTERY") {
      lcd.setCursor(0, 2); lcd.print("MODE: BATTERY         ");
    } else {
      lcd.setCursor(0, 2); lcd.print("NO SOURCE AVAILABLE   ");
    }
    currentSource = newSource;
  }
  lcd.setCursor(0, 3);
  lcd.print("Peak:"); lcd.print(isPeakHours ? "Yes " : "No  ");
  lcd.print(" B.Low:"); lcd.print(isBatteryLow ? "Yes" : "No ");
  // ----- تحكم يدوي دائم -----
  bool btnCritique = digitalRead(Button_Critique);
  bool btnSecondary = digitalRead(Button_Secondary);
  bool btnDefamable = digitalRead(Button_Defamable);
if (lastStateCritique == HIGH && btnCritique == LOW) {
    stateCritique = !stateCritique;
  }
  lastStateCritique = btnCritique;

  if (!isBatteryLow && lastStateSecondary == HIGH && btnSecondary == LOW)
{
    stateSecondary = !stateSecondary;
  }
  lastStateSecondary = btnSecondary;

  if (!isPeakHours && !isBatteryLow && lastStateDefamable == HIGH &&
btnDefamable == LOW) {
    stateDefamable = !stateDefamable;
  }
  lastStateDefamable = btnDefamable;
  // --- تنفيذ الحالات النهائية للأحمال ---
  digitalWrite(Relay_Critique, stateCritique ? LOW : HIGH);
  digitalWrite(Relay_Secondary, stateSecondary ? LOW : HIGH);
  digitalWrite(Relay_Defamable, stateDefamable ? LOW : HIGH);
  delay(50);
}
```

Abstract

This study delineates the design and execution of an intelligent hybrid energy system that guarantees an uninterrupted power supply by adeptly transitioning among solar energy, the public grid, and batteries. The system, governed by an Arduino board, examines real-time data from multiple sensors and prioritizes energy sources according to their availability.

A model farm near Ouargla served as a case study for analyzing energy consumption through theoretical calculations and electricity bills. A working prototype was constructed and tested in the field. Findings indicated enhanced energy reliability, optimal utilization of solar energy, and less reliance on the grid.

Keywords: Hybrid system – Solar energy – Arduino – Intelligent switching – Renewable energy – Model farm – Load management – Remote regions – Batteries

الملخص

تتناول هذه الدراسة تصميم وتنفيذ نظام طاقة هجين ذكي يضمن استمرارية تزويد الطاقة من خلال الانتقال الذكي بين الطاقة الشمسية، الشبكة العمومية، والبطاريات. يُدار النظام بواسطة لوحة أردوينو تقوم بتحليل البيانات اللحظية من مستشعرات متعددة وتحديد أولويات مصادر الطاقة حسب توفرها.

تم اعتماد مزرعة نموذجية بالقرب من ورقلة كدراسة حالة لتحليل استهلاك الطاقة من خلال الحسابات النظرية وفواتير الكهرباء. كما تم إنجاز نموذج عملي واختباره ميدانياً. أظهرت النتائج تحسنًا في موثوقية التزويد، واستغلالًا أمثل للطاقة الشمسية، وتقليلاً من الاعتماد على الشبكة.

الكلمات المفتاحية: نظام هجين – الطاقة الشمسية – الأردوينو – التبديل الذكي – الطاقات المتجددة – مزرعة نموذجية – إدارة الأحمال – المناطق المعزولة – البطاريات

Résumé

Cette étude présente la conception et la mise en œuvre d'un système d'énergie hybride intelligent assurant une alimentation électrique ininterrompue grâce à une transition efficace entre l'énergie solaire, le réseau public et les batteries. Le système, piloté par une carte Arduino, analyse en temps réel les données issues de plusieurs capteurs et priorise les sources d'énergie selon leur disponibilité.

Une ferme modèle située près de Ouargla a été choisie comme étude de cas pour analyser la consommation énergétique à partir de calculs théoriques et de factures d'électricité. Un prototype fonctionnel a été réalisé et testé sur le terrain. Les résultats ont démontré une amélioration de la fiabilité énergétique, une meilleure utilisation de l'énergie solaire et une réduction de la dépendance au réseau.

Mots-clés: Système hybride – Énergie solaire – Arduino – Commutation intelligente – Énergies renouvelables – Ferme modèle – Gestion de la charge – Zones isolées – Batteries