ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Smart Power Routing

Team #2

YUNFEI LYU (yunfeil3@illinois.edu)
JINGJING QIU (jqiu12@illinois.edu)
JIABAO SHEN (jiabaos3@illinois.edu)
XIAOYI HAN (xiaoyih2@illinois.edu)

TA: XXX

Wednesday 6th March, 2024

Contents

1 Introduction **1**
1.1 Problem . . . 1
1.2 Solution . . . 1
1.3 Visual Aid . . . 2
1.4 High-level Requirements List . . . 2

2 Design **3**
2.1 Block Diagram . . . 3
2.2 Subsystem Overview . . . 3
2.2.1 User Interface Subsystem . . . 3
2.2.2 Power Subsystem . . . 3
2.2.3 Control Subsystem . . . 3
2.2.4 Display Subsystem . . . 4
2.3 Subsystem Requirements . . . 4
2.3.1 User Interface Subsystem . . . 4
2.3.2 Power Subsystem . . . 4
2.3.3 Control Subsystem . . . 4
2.3.4 Display Subsystem . . . 5
2.4 Tolerance Analysis . . . 5

3 Ethics and Safety **7**
3.1 Ethics . . . 7
3.2 Safety . . . 7

References **9**

1 Introduction

1.1 Problem

In the evolving landscape of energy management, the "Smart Power Routing" project confronts not only the challenge of efficiently distributing and utilizing power among diverse devices but also the critical issue of maintaining stability in the power supply. Traditional energy systems exhibit significant shortcomings when faced with the dynamic nature of modern electrical demands, particularly in scenarios requiring the seamless operation of devices with varying energy needs. These systems often falter in dynamically managing power supply, leading to not just energy waste and inconsistent device functionality, but also to fluctuations that can compromise the stability of the entire power grid.

The stability of power supply is paramount, especially as we integrate more renewable energy sources and adopt more sophisticated electrical devices. The inherent variability in power generation from sources like wind and solar, coupled with the unpredictable nature of user interactions—such as switching devices on/off, plugging/unplugging, or even manually generating power introduces a level of complexity that traditional systems are ill-equipped to handle. This can result in voltage sags or surges that not only affect the performance and lifespan of household and industrial devices but also pose a broader risk to the integrity of electrical infrastructure. Our solution is a dynamic power management system that intelligently adapts voltage supply in real-time, responding to user interactions like switching devices or manual power generation. This project aims to demonstrate the practicality of smart power management in real-world scenarios, offering an accessible and engaging illustration of these principles for a broad audience.[1]

1.2 Solution

Our smart routing system manages and stores energy from electrical outlets and manual inputs — including hand-crank generators and a pneumatic turbine — into a battery. After receiving power information from the sensor, it then dynamically allocates power to a fan and light bulb in response to user interactions. The system's adaptability is managed by a microcontroller, which ensures efficient energy distribution and maintains device operation through variable conditions.

In greater detail, our smart routing system merges power harvested from electrical sockets with manually generated energy, utilizing hand-crank generators and a pneumatic turbine squeezed air pump—to efficiently convert mechanical energy into electrical power. The power is transferred to the electrical appliance and the excessive power is stored in a battery to ensure a stable supply. We also have an intuitive user interface, comprising switches and buttons that allow users to easily control the system, toggling the state of the socket, light, and fan, or activating the manual generators as needed. The operational demands of the fan and lightbulb are monitored by current sensors, which relay information on power consumption fluctuations to the microcontroller. This central processing unit, acting as the system's brain, analyzes the input from sensors and user interactions to dynamically adjust power distribution and output commands to transister-based circuits, ensuring that energy supply meets demand in real time and maintains uninterrupted device operation. Complementing this, an LED screen offers users a clear visual representation of the battery's storage levels and the real-time power usage of both the fan and lightbulb, highlighting the system's operational efficiency and the intricate power dynamics between the energy sources and the devices powered.

1.3 Visual Aid

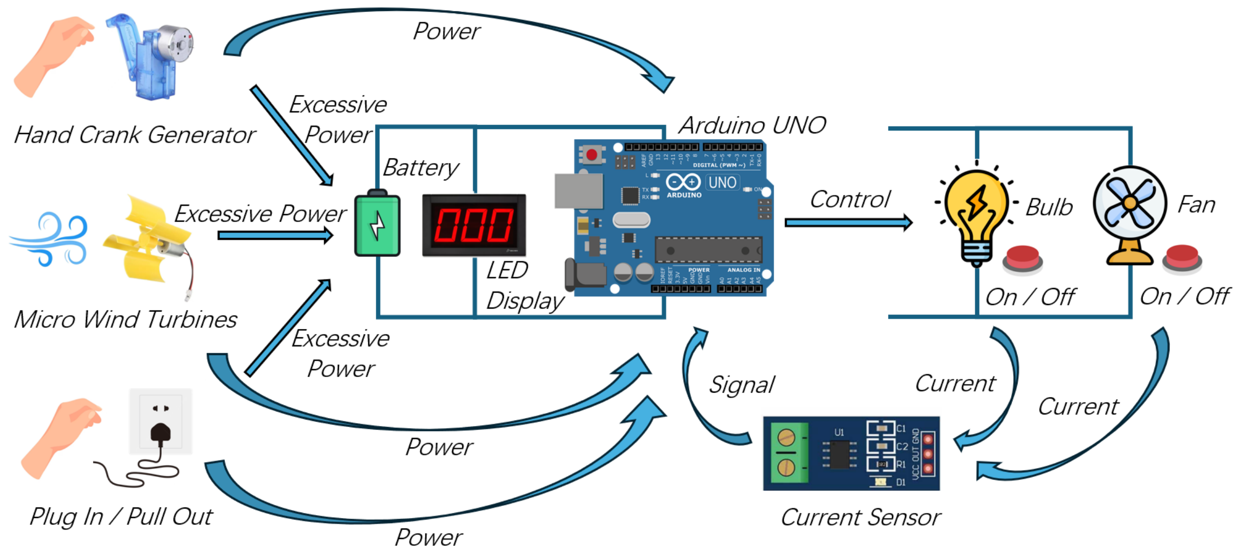

Figure 1: Visual Aid of Smart Power Routing

1.4 High-level Requirements List

- **Reliability:** The system should consistently maintain power levels within a ±1% fluctuation range to both the fan and the lightbulb regardless of user interactions, such as turning switches on and off and the presence of manual power generation from hand cranks or turbine inputs.
- **Efficiency:** It should maximize the energy harvested from manual inputs, targeting a minimum energy conversion and distribution efficiency of 90%.
- **Good Visualization:** The project should successfully demonstrate the principles of smart power routing in a way that is understandable and engaging for viewers, with clear displays of current power and battery condition.

2 Design

2.1 Block Diagram

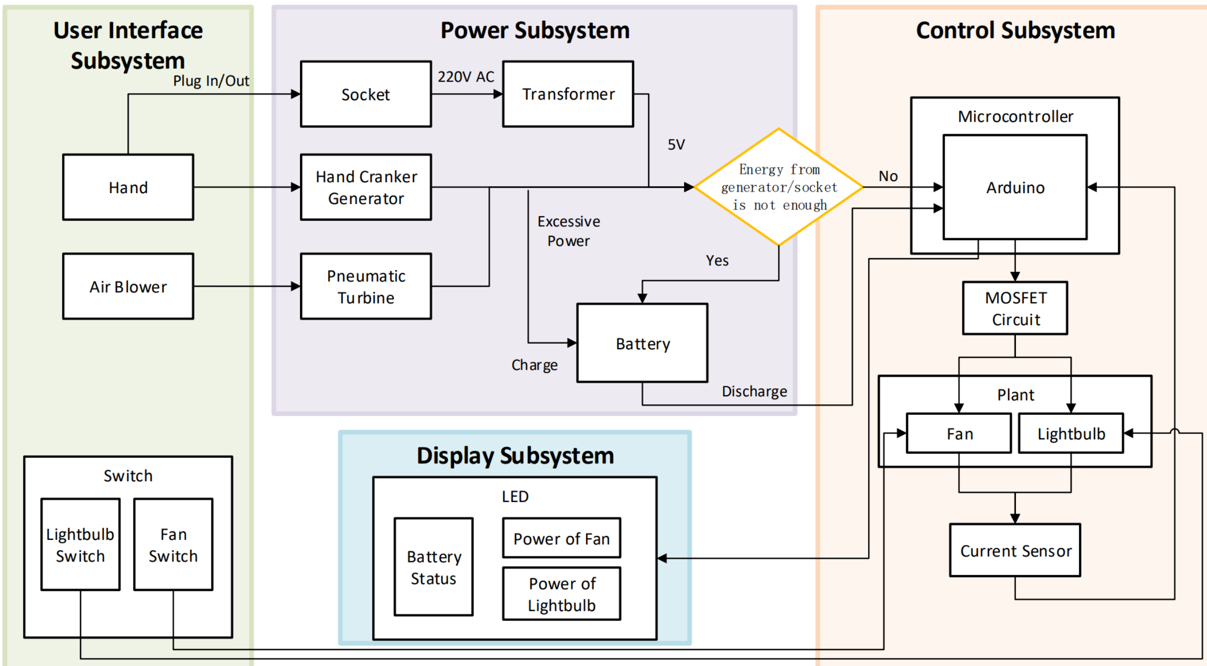

Figure 2: Block Diagram of Smart Power Routing

2.2 Subsystem Overview

2.2.1 User Interface Subsystem

The User Interface Subsystem serves as the interactive interface between the user and the system. It includes physical interfaces for plug in/out operations, a hand crank generator, and a pneumatic turbine, as well as switches for controlling the lightbulb and fan.

2.2.2 Power Subsystem

The Power Subsystem is responsible for providing and managing the electrical power. The system converts voltage from a 220V AC source via a transformer, accommodating power input from both the hand crank generator and the pneumatic turbine to power devices. It also includes a battery for storing excess electricity. When the energy input from the power sources is insufficient, the system compensates by supplementing power from the battery.

2.2.3 Control Subsystem

The Control Subsystem, with the Arduino microcontroller at its core, is tasked with receiving input signals from the User Interface Subsystem and the current sensor and managing the power stability for output devices including fans, lightbulbs, and LEDs. This subsystem also integrates a MOSFET circuit to regulate the power supply and utilizes a current sensor to monitor the electrical flow through the lightbulb and fan, conveying this data to the Arduino. Programming within the Arduino IDE will involve applying control algorithms such as Pulse Width Modulation (PWM) and Proportional-Integral-Derivative (PID) to finely tune the power supplied to the devices. Additionally, features like Analog-to-Digital Conversion (A/D) and serial communication will be included to facilitate real-time monitoring and intelligent management of the system's performance.

2.2.4 Display Subsystem

The Display Subsystem utilizes LEDs to indicate the battery status as well as the power status of the fan and lightbulb. This provides visual feedback through the user interface, keeping the user informed about the operational condition of the system.

2.3 Subsystem Requirements

2.3.1 User Interface Subsystem

- **Functional Requirements:** The system must provide an intuitive interface, including operations for power plug-in/out, manual generator, and pneumatic turbine.
- **Performance Requirements:** The user interface should be responsive with simple and intuitive operations, ensuring users can easily manage the system's power state.
- **Reliability Requirements:** All user interfaces must withstand long-term repetitive use and include design features to prevent accidental operation.

2.3.2 Power Subsystem

- **Functional Requirements:** The subsystem must be capable of harnessing power from a 220V AC source as well as from manual generators and pneumatic turbines, with effective management.
- **Performance Requirements:** The system must seamlessly switch to battery power during instability or interruption of the main power source, with a conversion efficiency exceeding 95%.
- **Reliability Requirements:** The system should have overload protection to prevent damage to devices or batteries due to excessive current.

2.3.3 Control Subsystem

- **Functional Requirements:** The system must be capable of receiving user inputs and managing the power stability of devices such as fans, lightbulbs, and LEDs. As the user adjusts the power input methods and the electrical devices being powered, the system must ensure the continuity and stability of the power supply, and intelligently adjust the power distribution to guarantee that each device operates at its optimal condition. Moreover, the system also needs to precisely control and monitor its operation, ensuring that energy efficiency and performance are optimized.

- **Performance Requirements:** The control system should have a command response time of no more than 1 second to ensure immediate feedback.
- **Reliability Requirements:** The system's design should consider future upgrades and expansions, maintaining compatibility with interfaces and programming.

2.3.4 Display Subsystem

- **Functional Requirements:** The system must include an LED display for battery status and the power state of fans and lightbulbs.
- **Performance Requirements:** The display must be clear and visible, even in low-light conditions.
- **Reliability Requirements:** The display devices should be resistant to environmental changes, such as dust and moisture.

2.4 Tolerance Analysis

- **Electrical Contact Resistance of Plugs and Switches:** The electrical contact resistance of plugs and switches is a crucial factor in the reliability of the power distribution system. Over time, contact resistance can increase due to factors such as corrosion, wear, and material degradation. To mitigate this risk, historical data on the longevity and performance of various plug and switch materials can be utilized. Additionally, rigorous testing protocols can be established to ensure that the chosen components will not exceed a resistance of 0.2 ohms, which is double the nominal value but still within a range that does not compromise performance. For instance, a switch with a nominal resistance of 0.1 ohms is considered robust if testing shows minimal resistance change over tens of thousands of cycles under load conditions similar to those expected in actual use.
- **Battery Capacity and Discharge Rate:** The battery subsystem is essential for ensuring a continuous power supply, especially when manual generation is not available. A battery's voltage output tends to decrease as it discharges, which can affect the operation of the connected devices. To address this challenge, the selected battery must have a flat discharge curve that maintains the voltage above a minimum threshold throughout its discharge cycle. For example, a 12V battery with a 5% voltage tolerance should not drop below 11.4V until it reaches the recommended depth of discharge. This can be ensured by selecting a high-quality battery with a proven discharge profile and by incorporating a voltage regulator that compensates for voltage dips as the battery discharges, thereby safeguarding device operation within the desired voltage range.
- **Arduino ADC Resolution:** The resolution of the Arduino's analog-to-digital converter (ADC) directly affects the precision of sensor readings, which in turn influ-

ences the control system's ability to make fine-tuned adjustments to power output. With a 10-bit ADC, there are 1024 discrete levels available, which means that for a 0-5V range, each level corresponds to approximately 4.88mV. When applied to a current sensor with a 0-5A output, this resolution translates to increments of about 4.88mA. Given the system's power stability requirement of ±1%, this resolution is adequate for representing small changes in current. To further refine the control system's response, software filters and averaging techniques can be applied to smooth out sensor noise and improve the fidelity of the sensor signal. This ensures more stable and accurate control of the power output to the fan and lightbulb.

3 Ethics and Safety

3.1 Ethics

- **Public Safety**: Ensuring the safety of the public is paramount in any engineering project. The IEEE Code of Ethics emphasizes the importance of prioritizing safety, health, and welfare of the public in professional activities [2]. Misuse or malfunctions of the smart power routing system could lead to electrical hazards, such as shocks, fires, or system failures.Therefore, we will put up warning signs and implement comprehensive safety protocols during system development and usage during system development and usage. We will integrate fail-safe mechanisms and emergency shut-off features to minimize the risk of accidents, ensuring the system is both safe and reliable for all users.

- **Academic Integrity and Citation**: Maintaining academic integrity involves ensuring all research and development work is conducted honestly, without plagiarism, and properly credits sources of knowledge and inspiration. The IEEE Code of Ethics highlights the importance of honesty in all professional endeavors [2]. We will rigorously follow academic citation practices, crediting all external sources of information, data, and ideas used in the development of the smart power routing system. Tools and processes will be implemented to check for inadvertent plagiarism, ensuring that all project documentation and publications accurately reflect the contributions of external sources.

- **Environemtal impact**: The development and use of smart power routing systems have potential environmental implications, including energy consumption and electronic waste. Efforts will be made to use sustainable materials and to design the system for easy recycling at the end of its life following the IEEE Code of Ethics [2].

3.2 Safety

- **Electric Shock Risk:** Handling live wires, especially when integrating manual generators and electrical outlets with 220 v power supply, poses a risk. The International Electrotechnical Commission(IEC) 60364 series sets forth standards for the electrical installations emphasizing the need for protective measures against electric shock and ensuring the safety of installations under both normal and fault conditions [3].Therefore, we should follow these regulations to ensure all components are properly insulated and implementing fail-safes to disconnect power in case of a short circuit are essential.

- **Overheating and Fire Risk:** The IEC 62368-1 states that equipment must be designed to prevent the risk of fire and overheating, even under fault conditions, by implementing safeguards such as thermal protection and limiting energy sources.[3] In our system, components such as batteries and microcontrollers can overheat, especially under continuous operation or fault conditions. It is essential that we use components within their rated capacities and incorporating thermal cutoffs to mitigate this.

- **Mechanical Safety:** The hand-crank generators and pneumatic turbines involve moving parts. We can follow guidance from ISO 12100 series, "Safety of machinery - General principles for design - Risk assessment and risk reduction." to use protective casings and guards to prevent injuy from moving parts.[4]

References

[1] Edubirdie. “”The Advantages of Adopting the Smart Electrical Grid”.” (Sep. 2022), [Online]. Available: https://edubirdie.com/examples/the-advantages-of-adopting-the-smart-electrical-grid/ (visited on 02/27/2024).

[2] IEEE. “”IEEE Code of Ethics”.” Accessed: 4 March 2021. (Jun. 2020), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html.

[3] International Electrotechnical Commission. “”Electrical regulations and standards”.” (2017), [Online]. Available: https://www.electrical-installation.org/enwiki/Electrical_regulations_and_standards.

[4] *ISO 12100:2010 - Safety of machinery – General principles for design – Risk assessment and risk reduction*, Status: Published. Publication date: 2010-11. Stage: International Standard to be revised [90.92]. Edition: 1. Number of pages: 77. Technical Committee: ISO/TC 199. ICS: 13.110, International Organization for Standardization, Nov. 2010. [Online]. Available: https://www.iso.org/standard/51528.html.