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Research article

Design and Implementation of a Power Dispatch Controller for Optimal Energy Management in a Grid-Connected System

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Abstract: Considering the sporadic nature of energy supply in Ghana, most communities have the main grid, solar Photovoltaic (PV) systems, and generators as their sources of power. The availability of these three individual electricity sources often necessitates the use of a manual power changeover. Manual changeovers often result in power mismatch and energy inefficiencies, resulting in the need for an automated power dispatch control system. This study explores the use of an Arduino Uno controller to fix this power mismatch and eliminate this inefficiency. This Arduino controller was used for the design of the dispatch control system, and the controlling algorithm was designed using Proteus software. The result of the simulation shows the ability of the system to alternate between prioritised and less prioritised electricity sources, depending on the availability of power, without interruption. The simulation results show the efficiency of the design to effectively dispatch power within 450ms without the need for human interference.

Keywords: Power dispatch, control system, PV, energy supply

1. Introduction

In developing countries like Ghana, energy management is an important aspect of the economy, especially when energy supply is erratic and unreliable. Electricity is important in every aspect of the economy, but unfortunately, there is a huge gap between power supply and power demand [1], [2]. This inconsistent supply of electricity over the years has caused many communities to adopt alternative sources to complement the main electricity grid. The most common alternative sources of electricity are solar Photovoltaic (PV) and diesel generators, with diesel generators becoming less attractive due to the high cost of fuel. Coupled with the main electricity grid, these systems form a hybrid energy infrastructure that necessitates efficient coordination to ensure an uninterrupted power supply. Despite the availability of this hybrid energy infrastructure, manual power changeovers are commonly used to switch between the sources of power

[3], [4]. Manual changeover systems are usually characterized by inefficiencies, such as delays in switching, power mismatches, and sometimes human errors [5], [6]. These shortcomings not only affect productivity and create inconvenience but also increase energy losses and reduce overall system reliability [7], [8], [9]. In this light, it is imperative to deploy an automated power dispatch controller capable of seamlessly alternating between these three power sources in an efficient energy management system.

The integration of renewable energy sources like solar PV systems with conventional energy sources is the foundation of common energy management approaches [10]. However, to achieve this important optimal utilization, sophisticated control mechanisms are needed. Considering the importance of uninterrupted power supply, a lot of research has been conducted to improve control mechanisms involved in a smooth energy transition. In [11], the authors designed and implemented a microcontroller-based power change-over switching system. The system employed a generator shutdown terminal that switched off the generator after the mains power supply had been restored. This process is controlled by a microcontroller that keeps sensing to detect the availability of power supply on the main supply line. The authors in [12] modelled an uninterrupted power supply to the load using auto selection between four different sources. Generator, solar panel, electricity mains, and inverters were considered as the four sources with a microcontroller 8051 for auto selection.

Arduino-based energy management systems have also been explored in [13], [14], [15], with the research focusing on using Arduino microcontrollers to optimize solar energy utilization through efficient load management. The focus of this research was to improve energy reliability by maintaining a consistent power supply. One of the significant limitations of existing Arduino-based energy management systems is the long switching delay associated with power source transitions. Several studies have implemented Arduino-based controllers for automated switching; however, many of these systems experience switching delays exceeding one second. This delay, though seemingly brief, can result in noticeable power interruptions, particularly in applications requiring seamless transitions, such as critical medical equipment, data centers, or industrial machinery. In [16], the authors used real-time power dispatch in hybrid systems that were implemented using Arduino boards to facilitate seamless energy distribution. These systems enabled adaptive power management to respond to dynamic energy demands. Existing power dispatch Arduino-based controllers typically initiate a switch between power sources as soon as they detect power availability without considering the quality or stability of the incoming power. This approach can lead to issues, particularly in scenarios where the incoming power is unstable or insufficient to meet the load requirements.

Many Arduino-based energy management systems are designed primarily for binary switching, where the system toggles between two predefined sources, which are typically the grid and a backup power system [17], [18], [19]. While this approach may work for basic applications, it lacks the flexibility to integrate additional renewable energy sources, such as solar or wind power. The rigidity of such systems limits their applicability in dynamic energy environments where multiple sources must be intelligently managed based on availability, stability, and cost-effectiveness [20]. The proposed design addresses this limitation by incorporating an adaptive control mechanism that allows for the seamless integration of multiple energy sources. This feature enhances the system's ability to prioritize renewable sources when available, thereby improving overall energy efficiency and reducing reliance on conventional grid power. This proposed research also aims to address these limitations by introducing a power dispatch controller that proactively evaluates the stability and capacity of the available power before initiating the switch. This algorithm will ensure that the incoming power is both stable and capable of supporting the load, reducing the risks associated with power fluctuations or insufficient supply that can occur in current automatic transfer switches (ATS) or dispatch controllers.

2. Methods

The key to moving from a developing country to a developed country in terms of socio-economic development for countries with significant energy challenges lies in effective energy management [21]. The frequency of brownouts and blackouts is a hindering block to the success of industries and institutions that support healthcare systems, education, and the general welfare of the citizens. Unfortunately, many countries in sub-Saharan Africa, including Ghana, often experience frequent outages owing to capacity limitations [22], [23], [24]. It is in this light that governments in Africa continue to advocate for the integration of alternative power sources to ensure energy reliability and sustainability. In Ghana, it is a common phenomenon to see communities or households using a hybrid energy infrastructure, namely the national grid, solar PV, and diesel generators. The main grid serves as the primary source of electricity, but its reliability is often affected by generation shortfalls, weak infrastructure, cable theft, and other human activities [25]. PV systems have also emerged as a renewable alternative, leveraging the region's abundant sunlight, but unfortunately, they are only available during the day [26]. Diesel generators, while dependable, are primarily used as backup sources due to their high operational costs and environmental impact [27]. Together, these energy sources form a critical infrastructure for meeting the diverse energy needs of communities.

2.1. Manual Power Changeover Systems

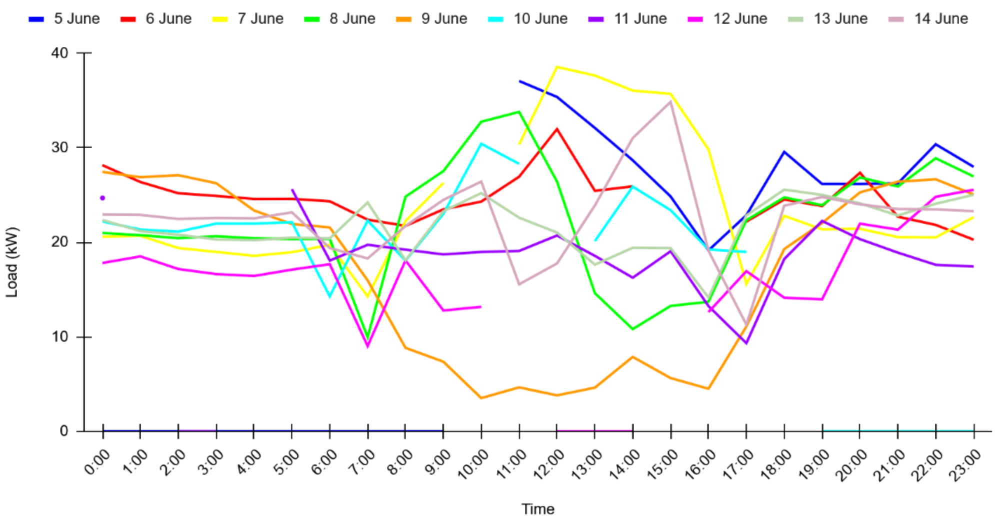
Despite the availability of this hybrid energy infrastructure, its effective utilization is negatively affected by the common use of manual power changeover systems. Manual systems require human intervention to switch between one power source to another, a process that is susceptible to power interruptions, inefficiencies, and errors. In the situation where there is a power disruption from the main grid, the time it takes to manually switch to a generator or solar PV and vice versa can disrupt power-dependent activities, resulting in economic losses and inconvenience. There is also a high tendency of power mismatch when manual changeovers are used, owing to the inability of the selected energy to meet the load requirement or operate inefficiently, wasting diesel or energy from PV or the grid. The numerous inefficiencies of manual changeover emphasise the need for an automated system that can alternate between several power sources seamlessly [28]. An automated power dispatch controller can efficiently prioritize energy sources based on availability, cost, and environmental impact, ensuring uninterrupted and optimal energy supply. An automated system not only enhances energy efficiency but also reduces dependency on manual intervention, thereby improving reliability and convenience.

2.2. Automated Power Changeover Systems

The introduction of an automated power dispatch control is a quintessential aspect of Ghana's energy solutions. The country's energy supply is characterized by inefficiencies, which require frequent alternating between several power sources. PV systems are only available during the day, while diesel generators are typically reserved for emergencies [28]. The national grid, despite its high accessibility, is often unreliable across the country, with the Northern region mostly affected. This dynamic energy characteristic is why a robust and adaptive control system is capable of alternating these transitions seamlessly. Although the concept of energy management using a control system is used worldwide, it has not been readily adopted in Ghana. Nonetheless, this cannot be done without analyzing the availability of resources, costs, and users' needs in Ghana's special energy context. Incorporating renewable energy sources such as solar PV systems into automated dispatch controllers represents an important advancement towards sustainable energy management practices [29]. Such systems can help to decrease emissions of greenhouse gases and help protect the environment by giving precedence to renewable sources in place of generators based on fossil fuels [30].

The design and implementation of an automated power dispatch controller require a number of technical elements and technologies [16]. At the core of the system is the microcontroller, which is the central processing unit of the proposed system. As a microcontroller for this work, Arduino Uno was chosen because of its affordability, multifunctionality and easy to program. The microcontroller, along with the sensors, is programmed to keep track of the status of the energy sources, select the primary ones according to fixed rules, and perform the transitions automatically. Sensors are used to collect information about each source's operational status and performance, and relays are used to connect and disconnect sources. The entire system is simulated using the Proteus software in order to test and compare its functionality and performance in different situations. The advantages of an automated power dispatch controller go beyond its convenience and dependability. This system minimizes the chances of human error while switching power sources through a seamless transition, eliminating laborious changeovers that usually come with power outages. This is crucial, for instance, in medical contexts where the availability of electricity is necessary for operating life-supporting devices. A power analyzer was installed on the distribution board of a facility with these independent sources of power for 2 weeks to understand the load profile and form the basis for the design. The data for the load profile is shown in Figures 1 and 2.

Figure 1. Load profile from 5 June to 14 June.



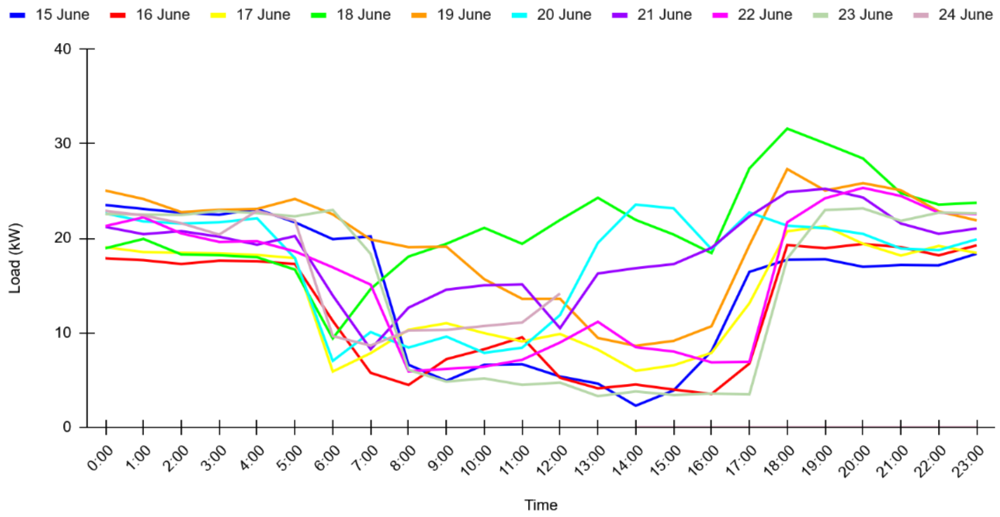


Figure 2. Load profile from 15 June to 24 June.

2.3. Component Selection

The components selected for the system's design were carefully chosen, such that the system could stand the test of time and serve the purpose of the implementation.

i. Arduino Mega Microcontroller

The microcontroller selected is shown in Figure 3. It has 14 digital input/output pins (of which six can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button.

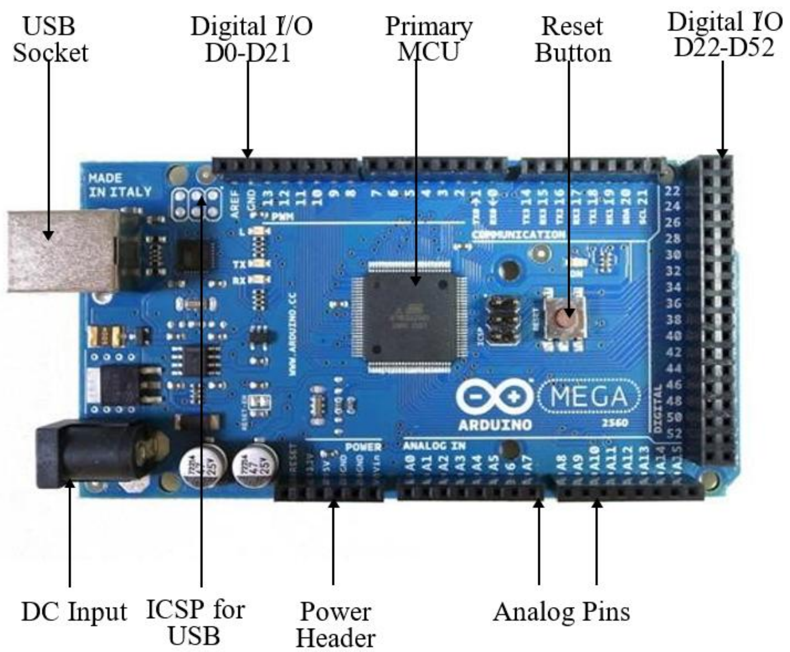
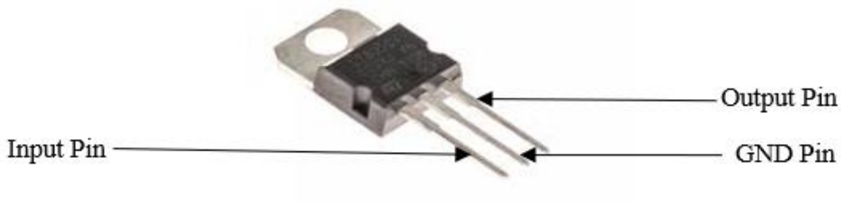


Figure 3. Arduino Mega Microcontroller.

ii. Voltage Regulator

The LM 337L is a three-terminal device that produces a positive output voltage for the system, that is, 5 V. This voltage is normally a regulated voltage. The input and output pins are at the extreme ends, while the central pin is for grounding. Figure 4 shows the selected LM 337L voltage regulator.

Figure 4. LM337L Voltage regulator.



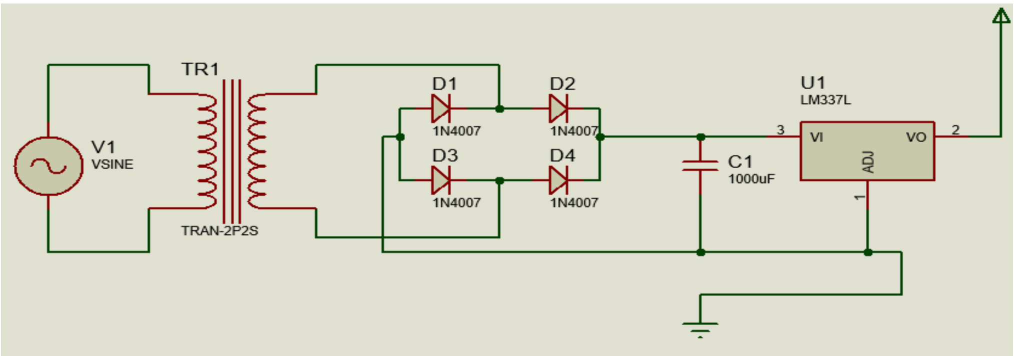
iii. Liquid Crystal Display
This study used a 16×2 LCD screen that displays the output of the system. All the instructions carried out by the system and the actions that the system takes are displayed on this screen. It displays 16 characters on two separate lines, operating on a command and data register.

iv. Relay
The relay selected should be able to withstand the total current that will be supplied to the loads in the community. From the measured load demand data, the peak load at the facility is 40 kW but was adjusted to 50 kW, and the calculated current is 86.95 A. An overload factor of 0.2 is considered, which results in a relay selection of 104.34A. This was calculated using equation (1).

$$I = \frac{\mathrm{P}}{\sqrt{3} \times V \times pf} \tag{1}$$

v. Power Supply Unit
The unit consists of a 12 V transformer, four diodes, a capacitor, and an LM337L voltage regulator. The transformer steps down the voltage from 240 V to 12 V, the diodes produce a rippled DC output, which is further filtered by the capacitor, and the LM337L regulates the voltage and maintains it at 5 VDC. Figure 5 shows the power supply circuit.

Figure 5. Power supply circuit for system design.



The value of the capacitor depends on the output voltage and output current. This can be calculated using the following procedure: The supplied voltage and frequency from the mains is 240 V and 50 Hz respectively while the voltage at the secondary transformer is 12 V_{rms}. The peak value of the transformed voltage and capacitance is calculated using Equations (2)-(6). The calculated peak voltage is 17V, and the capacitance is $1162.7\ \mu F$.

$$V_{peak} = \sqrt{2} \cdot V_{rms} \tag{2}$$

$$Q = CV = C(IR) = I \cdot t \tag{3}$$

$$C = \frac{I \cdot t}{V} \tag{4}$$

$$T = \frac{I}{f} \tag{5}$$

$$V = V_{peak} - 2V_{diode} - V_{min} \tag{6}$$

2.4. Model Design

The three sources (mains, solar, generator set) are connected as inputs to both the microcontroller and relays. The microcontroller is also connected to the relay driver, which closes a relay to allow the supply of power from the sources to the load or opens a relay to cut the supply of power from the sources to the load. The output of the microcontroller is also connected to the LCD screen, which displays the power source supplying power to the loads. Figure 6 shows the system operation flowchart, and Figure 7 shows a block diagram of the proposed design. The Arduino-based controller continuously monitors voltage, frequency, and current fluctuations of the available power sources. Voltage sensors (ZMPT101B) and current sensors (ACS712) are responsible for collecting real-time data from the grid and alternative sources, while frequency measurement is obtained using zero-crossing detection from an optocoupler circuit. The acquired analog signals are converted into digital form using the Arduino's ADC (Analog-to-Digital Converter). The moving average filtering is applied to reduce noise in the measured signals. The controller compares real-time measurements against predefined stability thresholds (voltage within 210–230 V, frequency within 49.5–50.5 Hz). If the grid power is stable, it remains the preferred source. Otherwise, the controller switches to an alternative power source (generator or solar). Hysteresis control is implemented to prevent frequent switching due to minor fluctuations.

Figure 6. System operation flowchart.

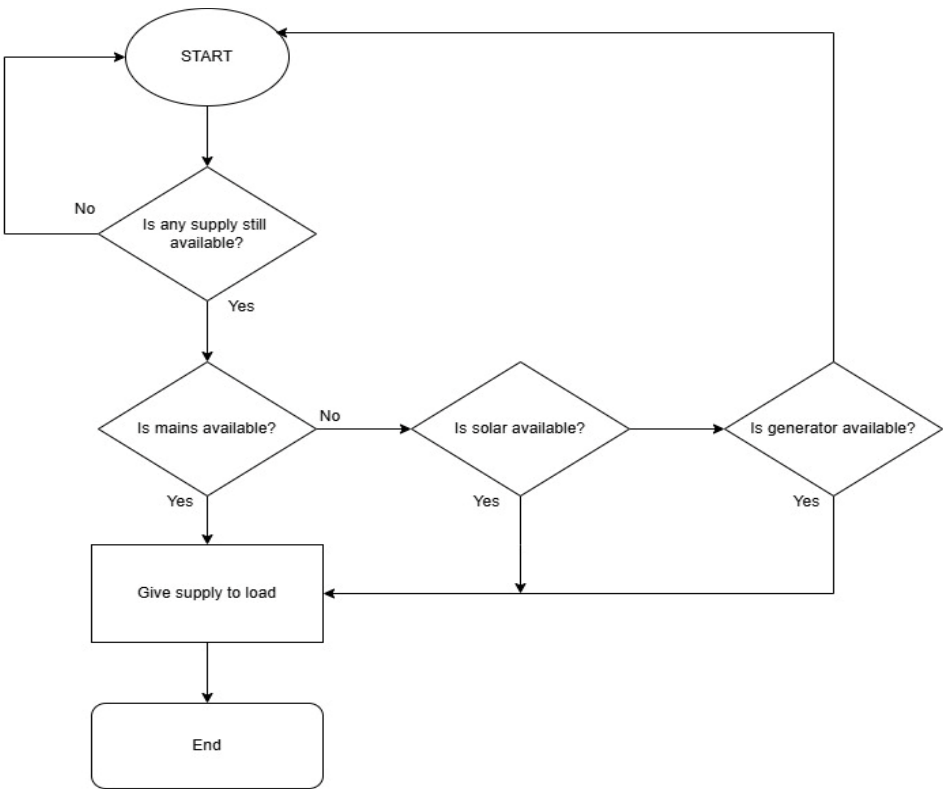
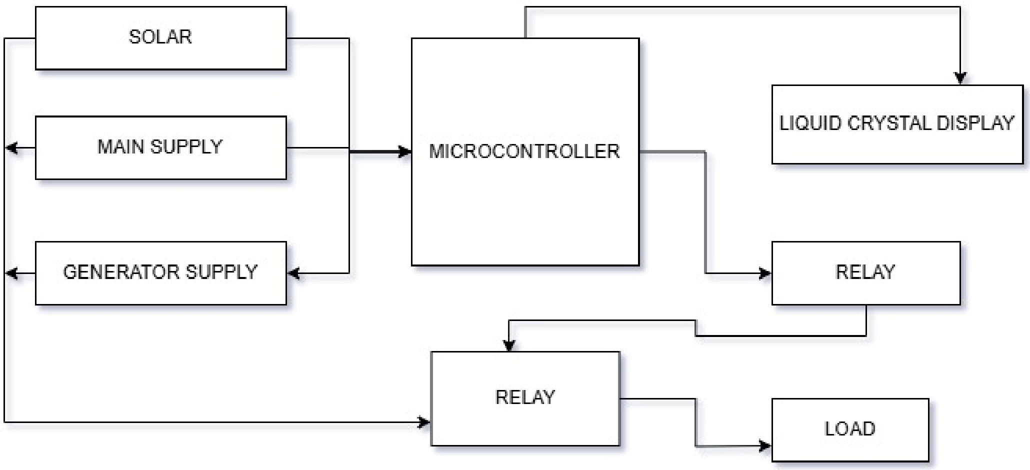


Figure 7. Block diagram of the proposed design.



The system begins by initializing the microcontroller and retrieving real-time voltage and frequency data from sensors. It continuously monitors the grid supply, ensuring that voltage remains within 220V ± 10V and frequency around 50Hz ± 0.5Hz. If deviations are detected, a stability timer is activated to determine whether the fluctuation is temporary or persistent. If instability persists beyond 5 seconds, the system checks the availability of a backup power source, such as a battery, inverter, or generator. Once a stable backup power source is confirmed, the relay control circuit disengages the grid and switches the load within 450 milliseconds, minimizing power interruption. The system continuously monitors both power sources, and when the grid stabilizes for at least 5 seconds, the load is switched back to the grid. If backup power fails while the grid remains unstable, an alert is triggered for manual intervention. This automated control process enhances power reliability, reduces downtime, and prevents unnecessary switching, ensuring seamless energy management.

3. Results and Discussion

The results are based on simulations of the system using the Proteus design suite. The results of the simulation were captured under four categories. These were when all three sources were available, when public utility was unavailable, when only the generator was available, and when the mains resumed in the absence of solar, as presented in Figures 8 to 11.

Figure 8. Results showing the availability of all three sources.

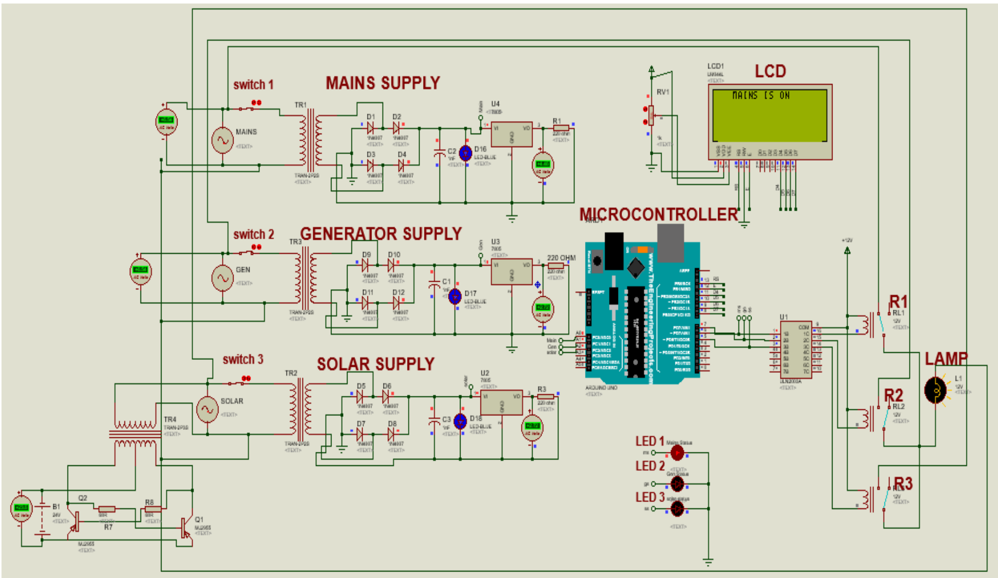


Figure 9. Indication of mains supply interruption.

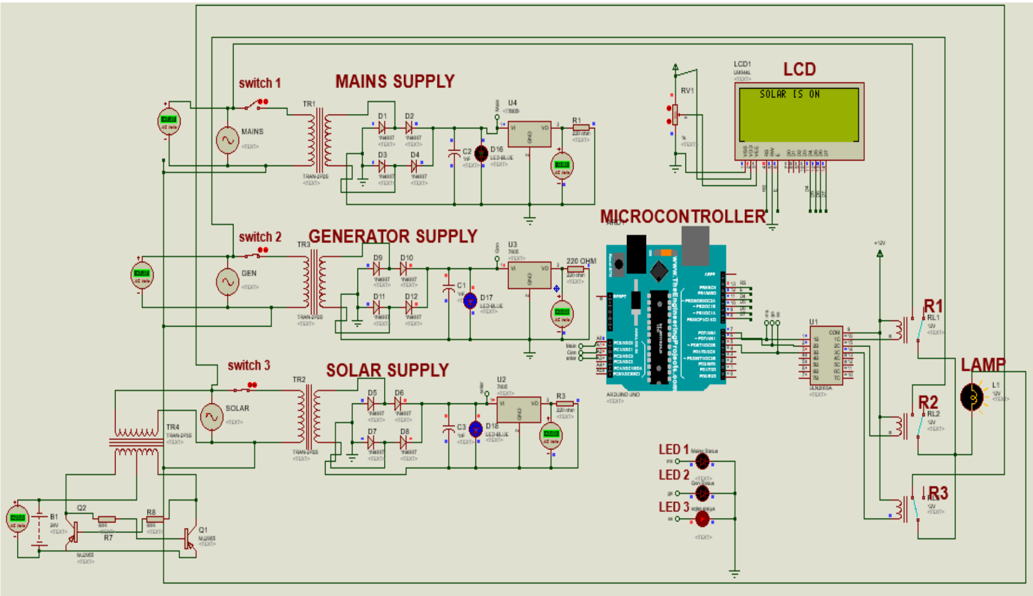


Figure 10. Indication of unavailability for both solar and mains power supply.

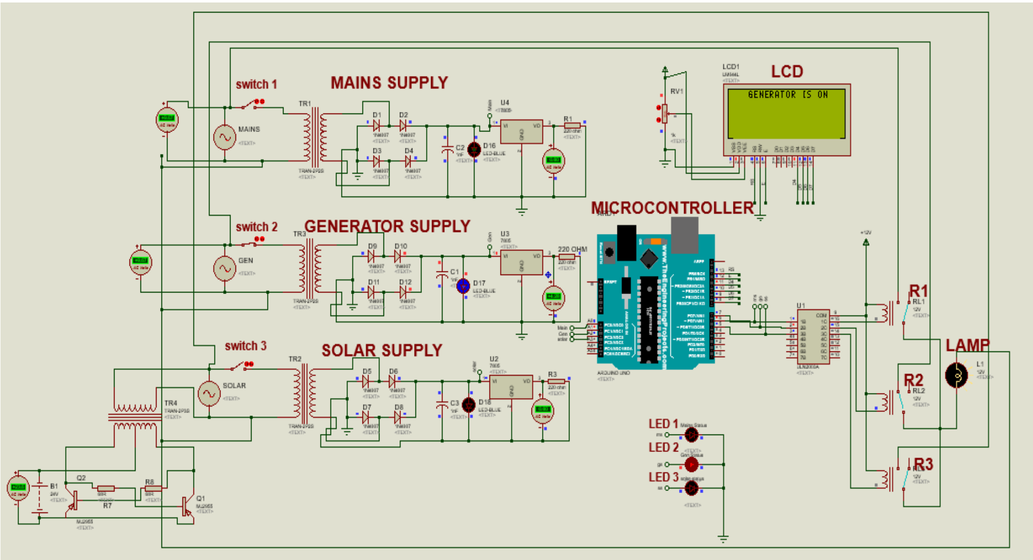
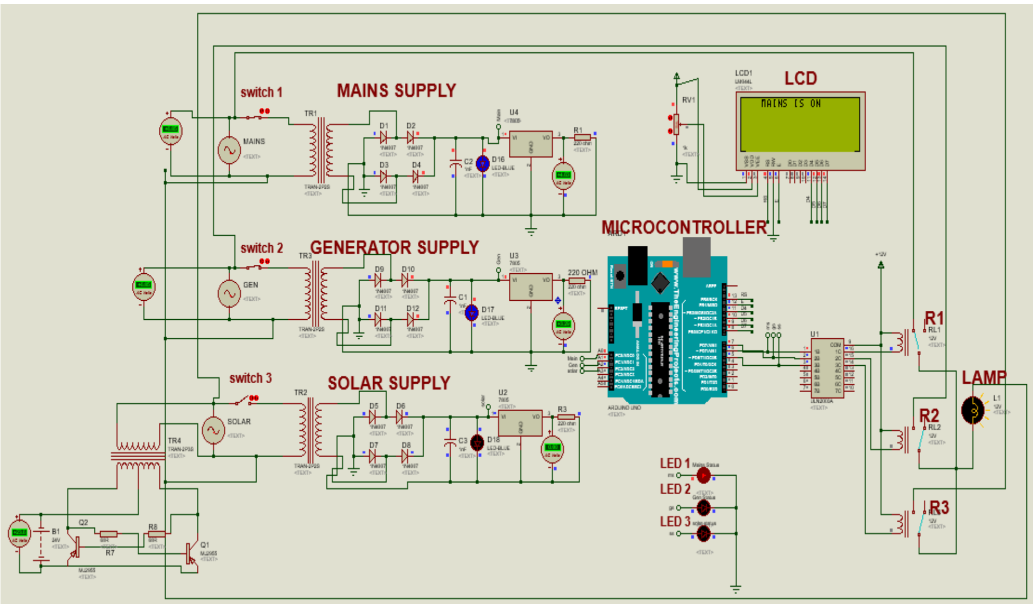


Figure 11. Indication of mains power supply restored.



The proposed circuit was successfully simulated using Proteus software. The simulation was carried out to verify the functionality of the design before any physical implementation could be carried out. When the system is in an ''ON'' state with all three sources of supply available, the mains relay closes, and the LCD displays “mains is on”. This means that mains or public utility is the source supplying power to the load, and that it has priority over the other two sources. In the absence of the mains or public utility, its relay opens, that of the solar supply closes, and the LCD displays “solar is on”. The action is simultaneous and instantaneous, such that the power supplied to the load is uninterrupted. This indicates that solar power is prioritized over the generator in the absence of a mains supply.

In the absence of both mains and solar supplies, the generator’s relay closes to connect the generator to supply power to the loads, and the LCD indicates “generator is on”. When either of the two sources (solar or mains) resumes, the system switches the relay of that source that has resumed to take over the supply of power to the load. It was also realized from the simulation that, in some situations, when a source of power “mains” resumes, its relay doesn’t close for it to take over the supply immediately, but delays for some time before the switching occurs. This is because the relay used checks for over- and under-voltages and only closes its contact when its design voltage is met. The occurrence of an over- or under-voltage can be observed with the aid of the voltmeter connected to the source, as shown in Table 1.

Table 1. Comparison of Performance Metrics.

Performance Metrics	Automated System	Manual Changeover
Switching Time	~450 ms	3–5 seconds
Energy Availability	98.7%	93%
Reliability (Success Rate)	~97%	~90%
Voltage Stability	±2V fluctuations	±15V fluctuations

4. Conclusion

This research focuses on addressing the challenges associated with the power mismatches and energy inefficiencies in Ghanaian communities, which often rely on a combination of main grid electricity, solar systems, and generators. An automated power dispatch system with a control algorithm developed in Proteus software was used for the simulation. From the simulation results, the proposed automated power dispatch controller selects the most available and prioritized source of electricity to power loads in the microgrid. Switching from one source of power to another source is done within the shortest possible time to avoid any interruptions to power flow. The system was designed to prioritize solar supply over the genset. This system offers a viable solution to improve energy management in grid-connected systems by eliminating manual changeovers that are currently in the system.

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Conflicts of Interest: The authors declare no conflicts of interest.

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