OPTIMIZING SOLAR POWER UTILIZATION THROUGH INTELLIGENT LOAD MANAGEMENT

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A PROJECT WORK SUBMITTED TO THE
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING,
FACULTY OF ENGINEERING,
UNIVERSITY OF BENIN.

IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD
OF BACHELOR IN ENGINEERING (B.ENG) IN
ELECTRICAL/ELECTRONIC ENGINEERING

APRIL, 2024.

CERTIFICATION

We, the undersigned, certify that this work was carried out by **OTUYOMA Oghenenyerhovwo Emmanuel, GIDEON Iyosayi Bazuaye, OKUNROBO Emmanuel Osamudiamen, CHIWUZO Nwachukwu Emmanuel, OVWEMU Oghenerukevwe Joy** in the department of Electrical and Electronics Engineering, Faculty of Engineering, University of Benin, Benin City. For the requirement of the award of the Bachelor of Engineering (**B.Eng**) Degree in Electrical and Electronics Engineering.

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Engr. Prof. K.O Ogbeide	
Head of Department	Date

DEDICATION

This project is dedicated to the supreme being who watches all, God Almighty.

ACKNOWLEDGEMENT

We want to acknowledge our families, whose unwavering emotional, mental, and financial support played a pivotal role in the accomplishment of this feat.

To our project supervisor, Dr. Sam, who pushed us to put in the needed work to get the job done, while providing guidance every step of the way, we say thank you.

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ABSTRACT

One of the most challenging problems associated with the use of solar energy in low-income households is the high initial cost of installation the bulk of which is the cost of the battery energy storage system.

The project was implemented using the ATMEGA 382P microcontroller due to its superior code efficiency, enabling throughputs up to ten times faster than conventional microcontrollers. The prototype, designed and simulated on Proteus, incorporated three loads connected within the system. Power was supplied by a DC Buck converter module, ensuring stable and efficient energy provision. This combination of advanced microcontroller technology, multiple load integration, and an efficient power source lays the groundwork for a robust and high-performing system.

Thorough incorporation of a rule-based algorithm using time of day and battery capacity as criteria in addition to proper classification of loads, the proposed system reduced the domestic energy usage and improved system availability. To verify the efficiency and robustness of the proposed algorithm, a test lab was set up, and the obtained results were compared in terms of total energy consumption, cost, the improved battery storage duration

CHAPTER ONE - INTRODUCTION

1.1 Background to The Study

The reliance on electricity generated from fossil fuels has made the Earth partially dependent on these finite resources. In the 18th and early 19th centuries, electricity was primarily used for lighting, but in the present global community, it's nearly impossible to lead a healthy life without electricity. Shockingly, almost half of the world's population, primarily in Africa and some Asian countries, lacks access to electricity (Bamisile et al., 2017)

Nigeria, as a major crude oil and natural gas producer, heavily depends on these conventional energy sources. However, diminishing fossil fuel reserves, inadequate refining capacity, and energy insecurity in volatile regions pose a significant risk of an energy crisis in the country (Ohunakin et al., 2014).

Despite having a population of about 170 million people and an abundance of diverse energy sources, Nigeria faces an energy paradox. Only approximately 50% of its population has access to electricity, and the rural population's access is even more limited, with an estimated 10% having reliable electricity services. In semi-urban and urban areas, there exists an 80% demand-supply gap, compelling most businesses to rely on self-generated electricity from diesel- or gasoline-powered generators. The transmission network struggles with overload issues, resulting in poor voltage profiles and the frequent system collapses, with reported losses conflicting with actual losses. Challenges include stagnant power generation capacity growth, inadequate maintenance procedures, and a lack of human capacity development. Fossil fuel-based generating plants dominate the current power mix, making standalone PV and solar thermal systems a viable, reliable, and, to a large extent, affordable alternative (Bamisile et al., 2017).

Every part of Nigeria, is relevant for modern off-grid solar products, providing stability even in grid-urban areas characterized by an unreliable network. Solar energy emerges as a stabilizing factor for Nigeria's energy supply system, offering a high potential source for diversifying energy sources and increasing the share of domestic energy supply, aligning with the objective of ensuring security of supply (Ohunakin et al., 2014).

The strength and future of a country's energy sector are intricately tied to its past, present, and future energy policies. These policies, established and integrated as a framework, manage social, economic, and environmental challenges related to energy production and consumption. The policy framework targets outcomes such as cleaner energy, smarter use of energy, secure and affordable energy, and economic growth from renewable energy use. The global push to reduce carbon emissions has elevated the encouragement of renewable energy, with solar energy being a common replacement for electricity and heating. Efficient solar policies can enhance energy efficiency, reduce oil imports, improve grid reliability, save money, decrease air pollution, create jobs, and lower energy prices (Bamisile et al., 2017).

Solar energy, abundant, pollutant-free, and geopolitically secure, holds promise for future energy needs. It can delivers more than the Earth uses in a year per hour and has the potential to meet global annual energy consumption in just 88 minutes. Nigeria, with an estimated daily solar energy potential of 17,459,215.2 million MJ, has yet to fully embrace solar energy despite its abundance (Ohunakin et al., 2014). Many residences in Nigerian are not powered from the national grid, and those that are often experience inadequate supply. Households resort to conventional generators, which are unsustainable in the long run (Adedeji et al., 2023). This lack of reliable electricity serves as an obstacle for grid-connected solar power. The current transmission grid, operating at 132 and 330 kV, covers only about 30% of the population, mainly in urban and semi-urban regions. Erratic electricity supply has led to increased reliance on alternative sources, and solar energy remains largely untapped, especially in residential and industrial sectors (Saka et al., 2017).

These challenges contribute to the high cost of housing development and ownership in Nigeria, making it financially burdensome for low-income earners, despite the potential of solar energy as an alternative source (Adedeji et al., 2023).

In remote and isolated places where extending the existing transmission grid network is impractical due to cost and technical challenges, the deployment of onsite generators often becomes the only feasible solution to meet the demand for electricity in homes not connected to the grid. Photovoltaic (PV) units are recognized as an effective means of providing electrical supply in off-grid installations, aligning with environmental goals, such as those set by the European Union. However, because PV-based generators behave in an unexpected and intermittent manner, it might be difficult to maintain a stable balance between generation and demand in off-grid residences.

To address this issue, a lot of end customers use backup devices like diesel engine generators (DEG) to guarantee a steady supply of electricity. These backup units do, however, add to pollution and are frequently costly. Empirical data indicates that the integration of storage facilities may effectively curtail fuel usage and improve the generation-demand balance in independent living units. It is not an easy task to efficiently and successfully manage storage facilities, backup generators, and renewable-based generators, particularly for residential consumers.

In recent years, the widespread development of Home Energy Management (HEM) systems has been motivated by this difficulty. These systems are capable of coordinating the use of several household appliances to meet predetermined objectives (Tostado-Véliz et al., 2021)

Renewable energy systems have garnered significant attention over the last three decades to reduce fossil fuel consumption, maintain a clean environment, and minimize short-term energy costs in residential houses. Photovoltaic (PV) panels and low-power wind turbines are widely used for electricity generation, with PV panels being increasingly integrated into smart buildings. However, PV systems face the challenge of irregular energy production, leading to potential shortfalls in meeting load demands at certain intervals during the day.

To address this issue, incorporating a battery bank into the system for residential applications becomes crucial. This allows surplus energy to be stored when generation exceeds consumption or vice versa, contributing to smart power management. The determination of the number of batteries is influenced by renewable energy generation, load profiles, and battery capacity (Tutkun, 2014).

In off-grid PV systems, increasing battery storage improves system availability, necessitating additional panels to generate surplus energy for storage. However, this approach increases installation costs, making it less feasible for residential or small-scale settings where batteries constitute a significant portion of solar installation costs. To minimize operational costs, power scheduling for short-term runs becomes essential, posing a constrained optimization problem for power scheduling in home residences.

The power scheduling problem has been the subject of research for the past three decades (Tutkun, 2014). A substantial portion of Nigeria's population lacks access to constant electricity, with some regions entirely cut off from the grid. In these regions, the deployment of off-grid/standalone PV systems become an attractive option. These systems typically include PV panels, storage batteries, and controllable and uncontrollable electrical loads. Optimal power scheduling is essential to achieve the lowest operational cost, considering various constraints inherent in the entire system (Tutkun & San, 2013).

Microcontroller-based studies on energy management systems have also been conducted. According to Barnicha, a Smart Home Energy Management System by is a home energy management system that uses an Arduino-based network to provide sensing, control, and smart algorithms with the use of renewable energy as a source of electricity at the residential level. It also gives homes precise information on their energy consumptions. A study by Hertzog, et. al., demonstrates an adaptable energy monitoring system that may be used to assess and analyze the performance of various solar modules. LabView was used to monitor and develop the output voltage and energy log from the data logged on a circuit interface using an Arduino Mega 2560 data logger to a personal computer with a front panel display (Galera & Llantos, 2017).

The project utilized the Arduino UNO R3 microcontroller and the Arduino IDE open-source development environment. This environment, which incorporates the Processing/Wiring language, enables the development of standalone interactive objects or connections to computer software. The design of embedded systems in this context focuses on essential characteristics and limitations to ensure efficient system operation. Therefore, the design of low-power communication-intensive real-time embedded systems must consider environmental and application constraints to enhance system efficiency, including real-time responsiveness and the execution of communication tasks (Galera & Llantos, 2017).

1.2 Problem Statement

Photovoltaic systems have a high initial cost of installation. It is projected that it will take between 8.7 and 16.9 years for solar household systems to catch up to traditional diesel generators in terms of electricity generation. Rural families cannot afford off-grid solar PV systems unless foreign subsidies are provided for these technologies. This high cost of photovoltaic system installation especially in residential settings is due to the high cost of energy storage devices.

Extensive research has been carried out to improve energy utilization for photovoltaic systems and microgrids at large. A method was proposed by Bouakkaz et al. to using a PV array and an ESS in a grid-connected home to lower the daily energy expenditure of smart home equipment while taking battery loss into account (Bouakkaz et al., 2020).

1.3 Significance of The Study

Much research has been done to solve the problem of optimizing energy consumption by loads in photovoltaic systems. In order to reduce the DC and the Peak-to-average ratio (PAR) by carefully planning the Home Appliance’s (HAs') activities, Mohammad et al. examined a HEMS equipped with a PV system, an Energy Storage System (ESS), and an EV battery storage (Mohammad et al., 2022). This bi-objective optimization problem was solved for the start times of Shiftable Home Appliances (SHAs) using the Grey Wolf optimization (GWO) algorithm. In this study, the HAs were supplied from the grid when the DEP was low, and if the ESS was not fully charged, it was also charged from the grid. When there was extra energy, it was sent to the grid when it was available and used to charge the ESS.

(Ahmad et al., 2017) used genetic algorithms (GA), binary particle swarm optimization (PSO), wind-driven optimization (WDO), bacterial foraging optimization (BFO), and hybrid GA-PSO algorithms to design a hybrid energy management system (HEM) with a photovoltaic system and energy storage system (ESS). The goal was to reduce the PAR and the DC. The day-ahead temperature, day-ahead solar radiation (SR), and day-ahead DEP were obtained using the utility; the optimization process did not take the user's comfort goal into consideration.

To potentially reduce electricity costs in households connected to the grid, (Dinh et al., 2020) suggested doing a second study on a hybrid energy management system (HEMS) in which the

ESS was merged with the PV system. Based on the day-ahead DEP and SR values obtained from the local utility, the best times to launch smart HAs were determined. The goal of this plan was to lower the total DC by storing energy for later use and selling it to the utility when the DEP was high. The BPSO algorithm was used in the suggested HEMS architecture since it is appropriate for smart HAs that turn on and off, while only the PAR and DC were considered in this study.

The main disadvantage of the proposed system is that the excess energy is sold directly from the battery to the utility, thus reducing the overall system efficiency. (Tutkun & Scarcello, 2023)

This research uses approach of using a multi-tiered approach to categorizing loads and based on available capacity of the Battery Energy Storage System (BESS), and time of day applied to a rule-based algorithm.

1.4 Aim

To design and implement a microcontroller based intelligent energy management system.

1.5 Objectives

1. Develop a three-tiered load prioritization scheme.
2. To develop algorithms for dynamic load scheduling and power allocation for each tier.
3. Implement mechanisms to monitor and assess the available capacity of associated energy storage system in real time.
4. To design and assemble the microcontroller-based Energy Management System and develop software for data acquisition, analysis and decision making based on available battery capacity and time of day.

1.6 Methodology

To achieve the objectives set out for the project, the following methods shall be carried out:

1. To develop a three-tiered load prioritization scheme, a comprehensive analysis of the types of loads, their criticality, and the available resources such as battery storage capacity will be conducted in order to define criteria for classifying the loads while considering factors like safety, functionality, and user preferences.
2. A tiered, rule-based, voltage-based load shedding algorithm with fixed thresholds for voltage and load shedding and divides the loads into critical, semi-critical and non-critical will be used, prioritizing essential functions.
3. Periodic measurement of the battery voltage will be carried out using a voltage sensor to estimate remaining battery capacity.
4. The ATmega328P microcontroller will be used to control the operations of the Energy Management System including analyzing and making decisions based on the data provided by the sensors.

CHAPTER TWO - LITERATURE REVIEW

2.1 Categorization of Appliances/Loads

From the perspective of load scheduling, home appliances can be divided into groups according to the way HEMSs handle them. Appliances are classified as either controllable or non-controllable in (Batista & Batista, 2018), depending on whether scheduling is possible for the operations of the appliance over a certain time period. The only thing you can do with appliances is set their start time; you cannot stop them from working or lower their energy usage. (Beaudin & Zareipour, 2015) suggest a more comprehensive classification that includes the subsequent six classes, each of which is intended to represent a distinct group of devices:

a. *Uncontrollable* loads – HEMS (Home Energy Management Systems) do not have the capability to modify or reschedule loads belonging to this particular class. This category encompasses electrical loads that offer additional benefits to homeowners and can be fully manipulated by the users themselves. Examples of such loads include, but are not limited to, entertainment devices like televisions, computers, and audio systems.

b. *Curtailable* loads – It is possible to modify energy usage of this load class during operation without greatly affecting the comfort of residents. These adjustments involve controlling energy consumption by altering settings without any compensatory actions. An instance of this is reducing the brightness of indoor lighting in response to natural daylight levels during the daytime.

c. *Uninterruptible* loads – Once initiated, loads in this class must complete their full cycle without interruption. As a result, the HEMS or residents can only control the start time of these loads. Common examples include dishwashers, washing machines, and clothes dryers.

d. *Interruptible* loads – Loads in this class can be paused at any point and then restarted with minimal effect on their functioning. Appliances belonging to this category are typically modelled as having a constant power draw, simplifying the mathematical formulation of the underlying scheduling problems. Examples include plug-in hybrid electric vehicles and other rechargeable devices.

e. *Regulating* loads – The operational states of appliances aim to closely match a specified reference set by residents or a Home Energy Management System (HEMS). Heating, ventilation, and air conditioning (HVAC) systems are examples of loads in this category.

f. *Energy Storage* – comprises appliances such as external batteries that store energy for subsequent use.

It should be stressed that no household appliance categorization scheme is currently globally accepted. It should also be pointed out that even among authors following the categorization proposed in (Beaudin & Zareipour, 2015), a consensus has not been reached yet on which appliances are assigned to each category.

2.2 Load Scheduling Techniques

When considering consumption shifting, selecting a specific scheduling method entails addressing multiple concerns. Scheduling occurs over a future timeframe where household electricity demands and generation can't be precisely forecasted, necessitating reliable and comprehensive consumption profiles. Furthermore, integrating uncertainties regarding future demands and generation is also essential.

Numerous approaches and strategies have been proposed to enhance energy efficiency via load scheduling (Bayram & Ustun, 2017; Beaudin & Zareipour, 2015). These methods can generally be classified into five categories:

Moreover, the optimization techniques employed for EMS modeling include:

- Classical mathematical programming methods;
- Methods based on an intelligent solution space search (metaheuristic methods);
- Rule-based methods (RBA);
- Multi-agent systems (MAS);
- Artificial intelligence (AI);
- Other approaches;
- Hybrid methods (a combination of several methods).

(Shareef et al., 2020) devised a wireless home energy management system designed to autonomously regulate household appliances for energy conservation, while prioritizing user comfort through a rule-based algorithm. Their setup comprises three primary components: appliance monitoring, control circuitry, and a central scheduling terminal, all interconnected via ZigBee wireless communication protocol. A smart plug oversees power usage, toggling appliances as needed, while a scheduling terminal, linked to a PC, enables users to input comfort preferences and access day-ahead pricing data.

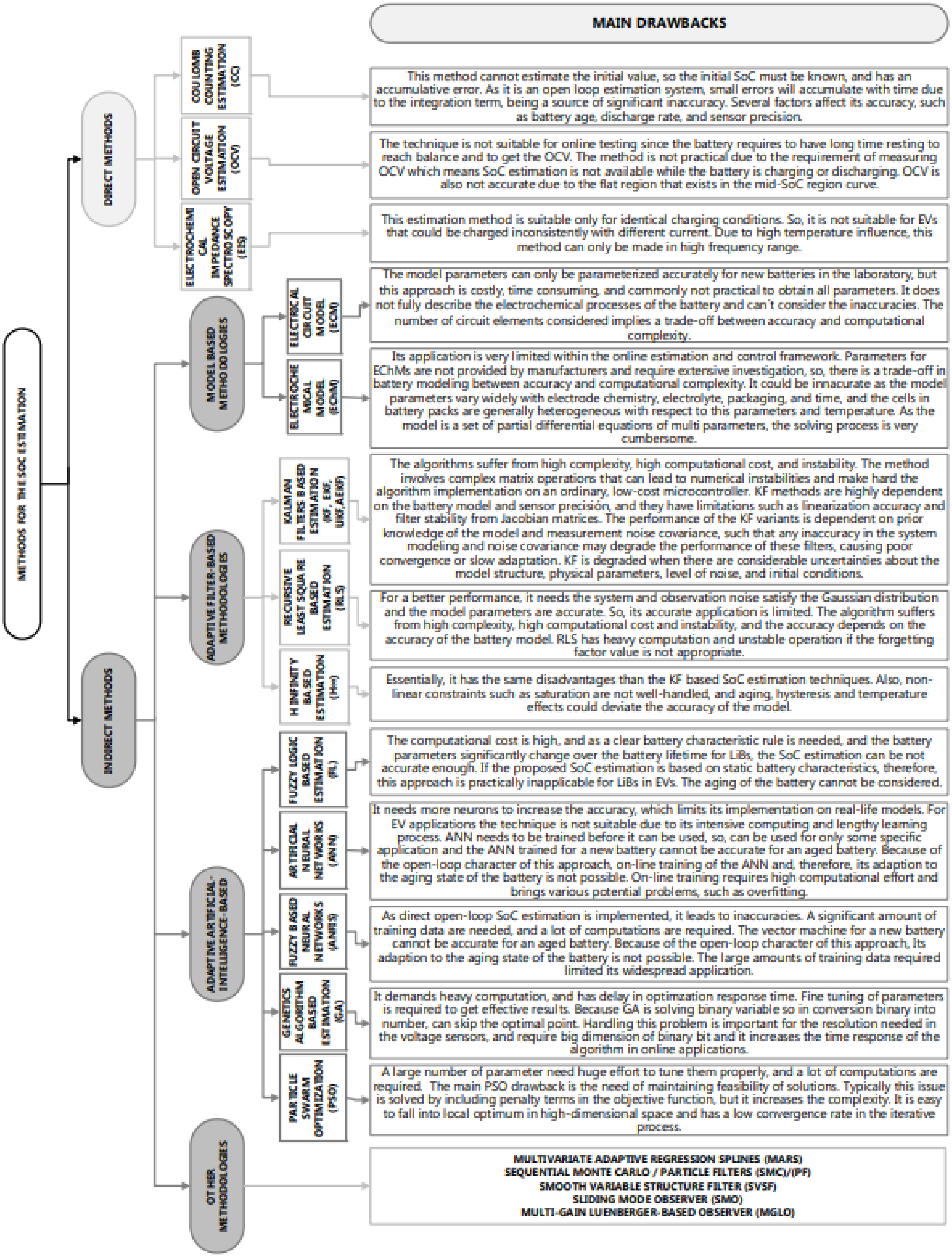
The experimental findings demonstrated that the central controller efficiently received data and managed multiple devices. Moreover, the system achieved notable reductions, amounting to a decrease of 23.5 kWh in both total daily energy consumption and the corresponding household bill.

While this work implements energy management strategies for a home connected to the grid alone to reduce the monthly utility bill, the proposed research project aims to apply similar concepts for an islanded or off-grid standalone solar PV system to optimize power availability in addition to reducing initial installation cost.

2.3 Battery State of Charge (SOC) Estimation

The State of Charge (SoC) serves as a crucial measure of the current condition of a battery, indicating the percentage of energy it currently holds compared to its most recent full charge. SoC reflects the available capacity within the battery that can be utilized. It offers users an approximate estimate of the duration until the battery is fully depleted. Moreover, an precise SoC is pivotal in enhancing a battery's operational dependability, prolonging its lifespan, and optimizing power management (Xing et al., 2014). It's typical to encounter a combination of both open circuit voltage (OCV) and coulomb counting (CC) techniques, with these blends often incorporating a range of enhancements in initial and real-time State of Charge (SoC) estimation. This integration is crucial as employing these methods individually may lead to inaccuracies. For instance, (Fleischer et al., 2013) integrated the OCV method algorithm, a full charge detector/dynamic load observer, and primarily the CC method with a robust extended Kalman filter algorithm (REKF).

In their paper, (Rivera-Barrera et al., 2017) proposed two categories (direct and indirect methods), and several subcategories that summarize trends in SoC estimation.



This method cannot estimate the initial value, so the initial SoC must be known, and has an accumulative error. As it is an open loop estimation system, small errors will accumulate with time due to the integration term, being a source of significant inaccuracy. Several factors affect its accuracy, such as battery age, discharge rate, and sensor precision.

The technique is not suitable for online testing since the battery requires to have long time resting to reach balance and to get the OCV. The method is not practical due to the requirement of measuring OCV which means SoC estimation is not available while the battery is charging or discharging. OCV is also not accurate due to the flat region that exists in the mid-SoC region curve.

This estimation method is suitable only for identical charging conditions. So, it is not suitable for EVs that could be charged inconsistently with different current. Due to high temperature influence, this method can only be made in high frequency range.

The model parameters can only be parameterized accurately for new batteries in the laboratory, but this approach is costly, time consuming, and commonly not practical to obtain all parameters. It does not fully describe the electrochemical processes of the battery and can´t consider the inaccuracies. The number of circuit elements considered implies a trade-off between accuracy and computational complexity.

Its application is very limited within the online estimation and control framework. Parameters for EChMs are not provided by manufacturers and require extensive investigation, so, there is a trade-off in battery modeling between accuracy and computational complexity. It could be innacurate as the model parameters vary widely with electrode chemistry, electrolyte, packaging, and time, and the cells in battery packs are generally heterogeneous with respect to this parameters and temperature. As the model is a set of partial differential equations of multi parameters, the solving process is very cumbersome.

The algorithms suffer from high complexity, high computational cost, and instability. The method involves complex matrix operations that can lead to numerical instabilities and make hard the algorithm implementation on an ordinary, low-cost microcontroller. KF methods are highly dependent on the battery model and sensor precisión, and they have limitations such as linearization accuracy and filter stability from Jacobian matrices. The performance of the KF variants is dependent on prior knowledge of the model and measurement noise covariance, such that any inaccuracy in the system modeling and noise covariance may degrade the performance of these filters, causing poor convergence or slow adaptation. KF is degraded when there are considerable uncertainties about the model structure, physical parameters, level of noise, and initial conditions.

For a better performance, it needs the system and observation noise satisfy the Gaussian distribution and the model parameters are accurate. So, its accurate application is limited. The algorithm suffers from high complexity, high computational cost and instability, and the accuracy depends on the accuracy of the battery model. RLS has heavy computation and unstable operation if the forgetting factor value is not appropriate.

Essentially, it has the same disadvantages than the KF based SoC estimation techniques. Also, non-linear constraints such as saturation are not well-handled, and aging, hysteresis and temperature effects could deviate the accuracy of the model.

The computational cost is high, and as a clear battery characteristic rule is needed, and the battery parameters significantly change over the battery lifetime for LiBs, the SoC estimation can be not accurate enough. If the proposed SoC estimation is based on static battery characteristics, therefore, this approach is practically inapplicable for LiBs in EVs. The aging of the battery cannot be considered.

It needs more neurons to increase the accuracy, which limits its implementation on real-life models. For EV applications the technique is not suitable due to its intensive computing and lengthy learning process. ANN needs to be trained before it can be used, so, can be used for only some specific application and the ANN trained for a new battery cannot be accurate for an aged battery. Because of the open-loop character of this approach, on-line training of the ANN and, therefore, its adaption to the aging state of the battery is not possible. On-line training requires high computational effort and brings various potential problems, such as overfitting.

As direct open-loop SoC estimation is implemented, it leads to inaccuracies. A significant amount of training data are needed, and a lot of computations are required. The vector machine for a new battery cannot be accurate for an aged battery. Because of the open-loop character of this approach, Its adaption to the aging state of the battery is not possible. The large amounts of training data required limited its widespread application.

It demands heavy computation, and has delay in optimzation response time. Fine tuning of parameters is required to get effective results. Because GA is solving binary variable so in conversion binary into number, can skip the optimal point. Handling this problem is important for the resolution needed in the voltage sensors, and require big dimension of binary bit and it increases the time response of the algorithm in online applications.

A large number of parameter need huge effort to tune them properly, and a lot of computations are required. The main PSO drawback is the need of maintaining feasibility of solutions. Typically this issue is solved by including penalty terms in the objective function, but it increases the complexity. It is easy to fall into local optimum in high-dimensional space and has a low convergence rate in the iterative process.

Figure 2.1: Classification of methods of estimating- battery SoC

a. Coulomb Counting Estimation (CC)

The coulomb counting (CC) method has been established as an industry standard for estimating State of Charge (SoC) (Lashway & Mohammed, 2016). Currently, the CC method, also referred to as the ampere-hour balancing method, is widely employed for SoC estimation due to its high accuracy, particularly for short-term calculations. According to (Fleischer et al., 2013), the CC method defines SoC as:

$$SoC(t) = SoC(t_0) + \frac{1}{C_n}\int_{t_0}^{t_0+t} I_{bat}(d\tau) \times 100\%$$

where $SoC(t_0)$ is the initial SoC, C_n the nominal capacity, and I_{bat} is the charging/discharging current. The coulomb counting (CC) method, though straightforward, presents challenges such as initial value errors and accumulated inaccuracies. Therefore, it's crucial to consider the following issues: The measurement of battery current can be both imprecise and susceptible to noise interference. These inaccuracies stem from limitations in sensors, such as resolution and rounding, which are crucial for maintaining precision over time. Consequently, supplementary algorithms are necessary. Charging or discharging currents should be integrated over time to determine the Constant Current (C.C) based on when the State of Charge (SoC) was last determined. However, it's important to note that this method doesn't resolve the issue of accumulating errors nor is it resilient to errors in the initial SoC estimation. Even a slight deviation from the correct value at the outset could compromise subsequent estimates, making subsequent adjustments challenging. While the CC method has largely fallen out of favor as a standalone criterion, it's often used in conjunction with other measures rather than being relied upon as the sole basis for estimating system-on-chip design efforts.

b. Open Circuit Voltage-Based Estimation (OCV)

Commonly utilized methods for estimating State-of-Charge typically revolve around defining the Open Circuit Voltage (OCV) curve. This can be achieved through polynomial approximation or by employing a lookup table. Subsequently, these methods either directly invert the OCV curve (when steady-state voltage measurement is feasible) or utilize a model-based approach incorporating cell characteristics (Lavigne et al., 2016). Employing voltage measurements to ascertain SoC for the cell enables us to establish the relation:

$$SoC = f^{-1} (OCV)$$

The Open Circuit Voltage (OCV) method involves continuously monitoring the voltage across a cell, which is then utilized to determine the state of charge (SoC) based on a predetermined table. However, there are certain drawbacks associated with this approach. The sensors require high resolutions to ensure precise voltage measurements and sufficient time for system stabilization. While this technique may yield accurate results due to fixed OCV values per cell type, its reliance on rest periods prevents its use in real-time applications for SoC estimation.

2.4 Overview of Energy Management Systems (EMS)

Home Energy Management Systems (HEMS), Integrated Energy Management Systems (IEMS), Smart Energy Management Systems (SEMS), and Centralized Energy Management Systems (CEMS) represent various types of EMS, among numerous others, with a specific focus on enhancing the production and consumption of reliable and cost-efficient energy. Techniques such as SSM and DSM are employed within these systems to optimize energy usage. Energy management has long been a fundamental concept involving monitoring energy consumption, identifying areas of inefficiency, and implementing strategies to mitigate energy wastage. EMSs primarily aim to balance supply and demand within electrical grids, a critical consideration, particularly in grids incorporating intermittent renewable sources like solar energy (Falope et al., 2024). Utilizing intricate software and hardware components, EMSs monitor, control, and optimize energy usage to minimize costs (Marwan et al., 2021). For smart grid applications, (Zhao et al., 2021) stress that EMS leverages tools such as SM, sensors, and other detection devices to achieve five main objectives: cost minimization, optimization of load curves, reduction of CO2 emissions, maximization of renewable energy outputs, and enhancement of user comfort. These objectives fall under the overarching frameworks of economy (cost savings), environment, and human comfort (Falope et al., 2024).

EMS is broadly categorized into two types: predictive energy management system (PEMS) and real-time energy management system (REMS) (Shakeri et al., 2018). PEMS utilizes historical data to forecast loads, energy supplies, or a combination of both, ensuring optimal alignment between supply and demand. However, since forecasting is not entirely precise, real-time load scheduling is necessary to account for prediction errors. Conversely, REMS employs real-time algorithms to adjust load or supply control based on SSM or DSM parameters.

A HEMS could potentially lower electricity operational costs by 23.1% or decrease residential peak demand by 29.6%. Additionally, employing HEMS offers benefits such as minimizing energy wastage, reducing the need for household intervention, promoting eco-friendliness, and enhancing resident well-being (Beaudin & Zareipour, 2015).

2.4.1 Components of EMS

a. *Sensing and measuring devices* – used to measure physical quantities, such as temperature, humidity or light, or to detect motion or room occupancy, just to name out a few. Smart meters are commonly used by HEMSs, collecting detailed energy consumption of individual appliances and other human activities-related information. Smart meters also facilitate two-way communication between HEMS and the utility.

b. *Smart appliances* – consist of typical household devices (e.g., dishwashers, refrigerators or air conditioning units), enhanced with computing and communication capabilities. Energy generation devices such as photovoltaic (PV) panels and wind turbines are also considered. Smart appliances communicate with a central platform, which handles all measured data and coordinates appliance uses.

c. *User interface* – a device via which residents can interact with the HEMS. Interfaces can be used to display information, such as current consumption or energy expenses, and for specifying residents' preferences, including appliance priorities, comfort parameters or scheduling goals. Touch screen or mobile application interfaces are very common, although other less user-friendly options, e.g. a computer terminal, can also be considered.

d. *Central platform* – aims at managing and optimising energy usage. It receives smart meter information and adopts a scheduling mechanism, usually computed via an optimisation approach, assuming a given performance index. Energy bill is a common choice, along with comfort, peak reduction and GHG emissions.

2.5 Types of Residential Solar Installations

i) Grid-tied installations

ii) Standalone or Off Grid Installations

2.5.1 Grid-tied installations

A *grid-connected PV system* is one where the photovoltaic panels or array are connected to the utility grid through a power inverter unit allowing them to operate in parallel with the electric utility grid. Solar-powered PV systems can sometimes produce more electricity than is needed or consumed, especially during the long hot summer months. This extra or surplus electricity is either stored in batteries or as in most grid-connected PV systems, fed directly back into the electrical grid network. In other words, homes and buildings that use a grid-connected PV system can use a portion or all of their energy needs with solar energy, and still use power from the normal electrical mains grid during the night or on cloudy dull and rainy days, giving the best of both worlds. Then in *grid-connected PV systems*, electricity flows back and forth to and from the mains grid according to sunlight conditions and the actual electrical demand at that time.

The main advantage of a grid-connected PV system is its simplicity, relatively low operating and maintenance costs as well as reduced electricity bills. The disadvantage however is that a sufficient number of solar panels need to be installed to generate the required amount of excess power.

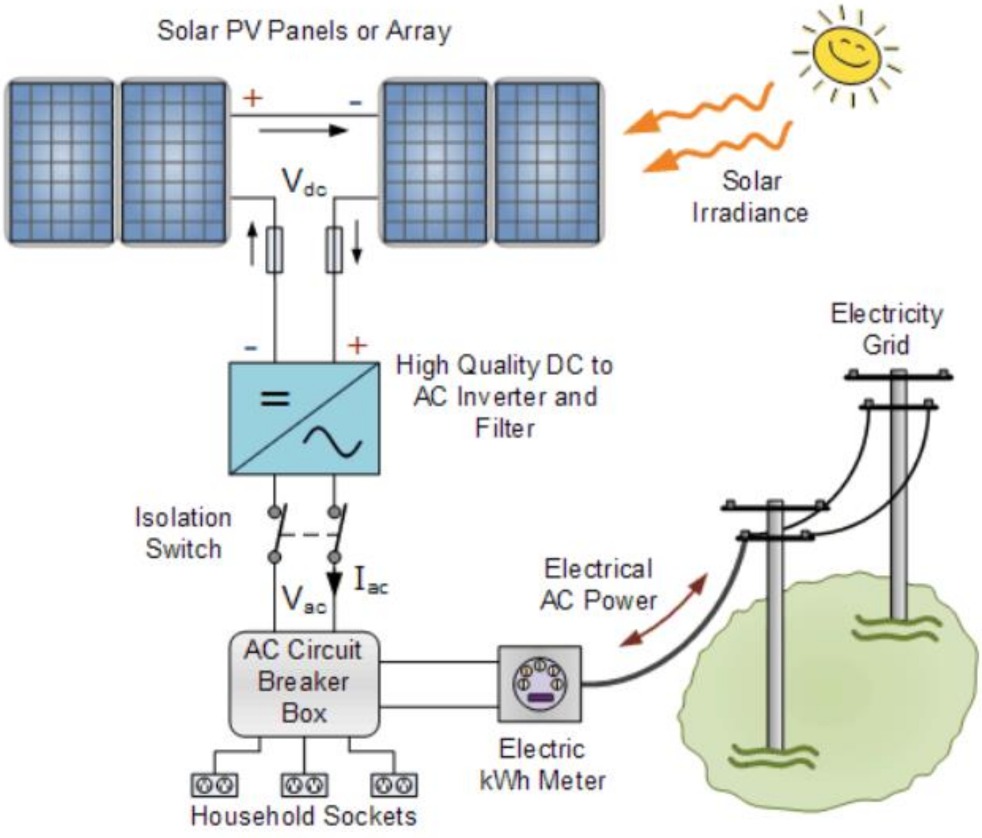


Figure 2.2: Simplified illustration of a grid-connected PV system

Grid-connected systems with integrated battery storage operate alongside local electricity providers, ensuring short-term peak demands are met by the battery, reducing reliance on the grid and avoiding additional charges. In grid-connected PV setups, batteries serve short-term storage needs for hours or days to weather bad conditions and long-term storage for weeks to compensate for seasonal solar variations. While incorporating batteries increases system complexity and cost, it's invaluable for homeowners in remote areas prone to grid outages during bad weather conditions or when there are essential electrical power needs that can't afford interruption.

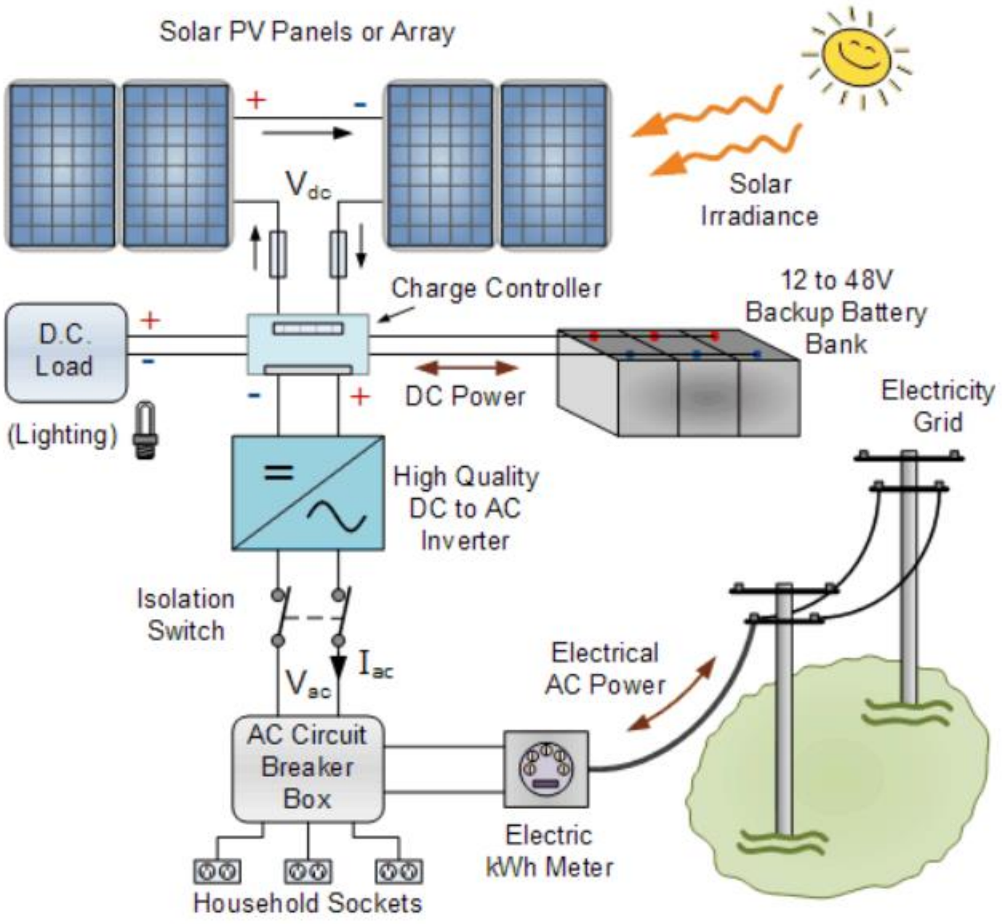


Figure 2.3: Illustration of a Grid Connected PV system with Battery Storage

2.5.2 Standalone or Off-Grid PV Installation

A self-sufficient off-grid solar PV system autonomously produces electricity during daylight hours to charge batteries for later use when solar energy isn't available. These compact setups utilize rechargeable batteries to store energy generated by PV panels. Particularly fitting for remote rural regions or situations where conventional power sources are unfeasible, standalone PV systems supply electricity for lighting, appliances, and various needs. In such scenarios, opting for a standalone PV system proves more economically viable than extending power lines from the local utility as part of a grid-connected PV system.

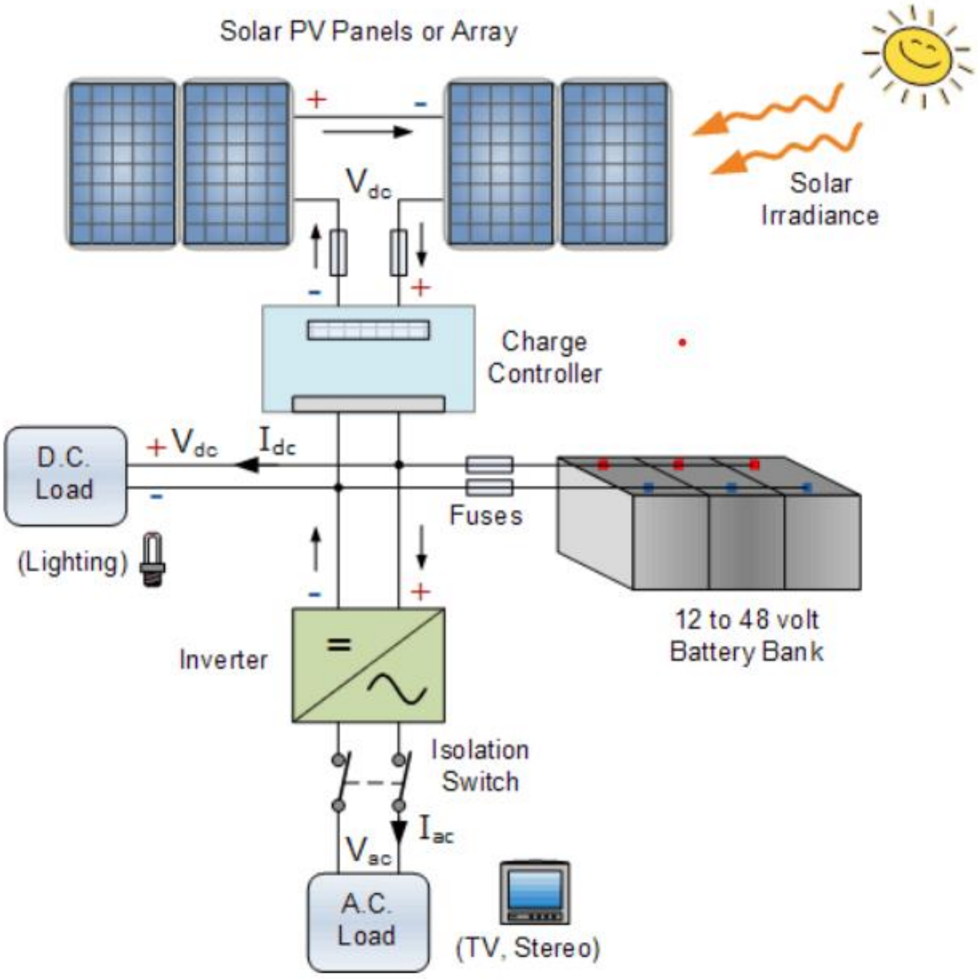


Figure 2.4: Illustration of a stand-alone PV system

2.6 Review of Components Used

1. Real-Time Clocks

A real-time clock (RTC) is a hardware component that keeps track of the current time even when the main system, like a microcontroller, is turned off. It maintains the clock by counting the oscillations of a dedicated oscillator circuit, typically using an external 32.768 kHz crystal oscillator, an internal capacitor-based oscillator, or an embedded quartz crystal. Some RTCs can also detect transitions and count the periodicity of an input signal connected to them.

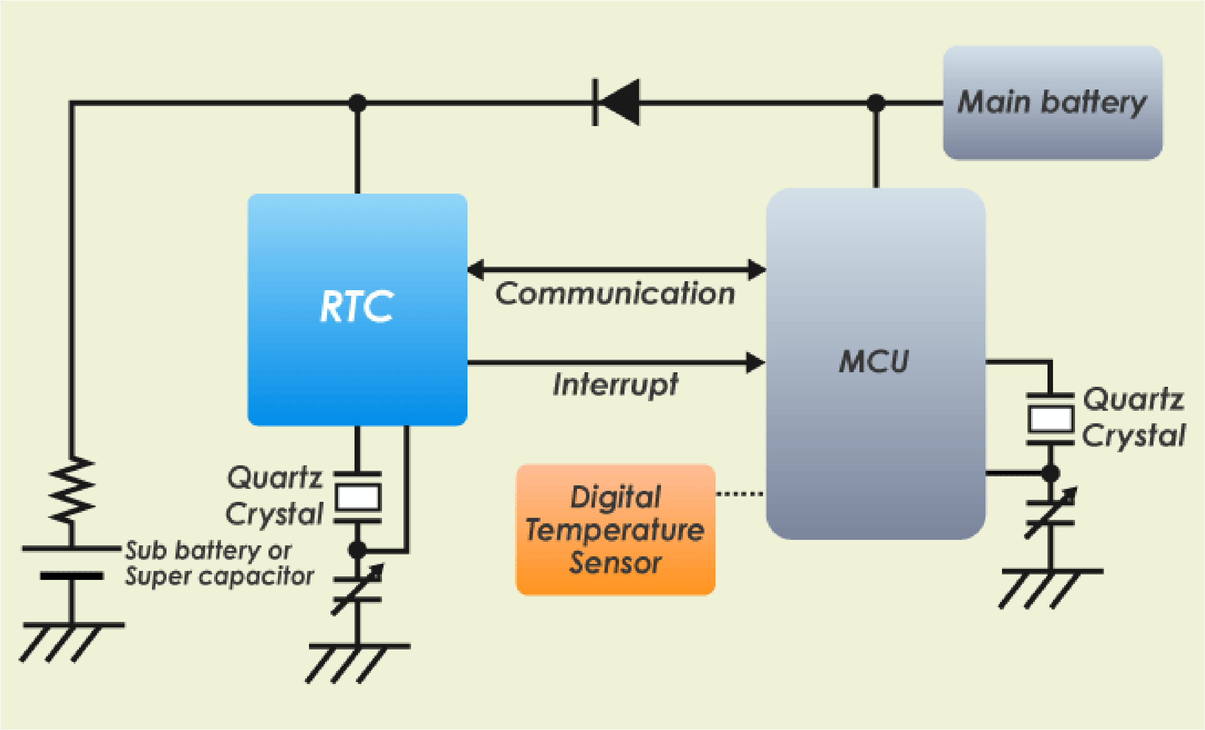


Figure 2.5: Schematic diagram showing how a real-time clock is connected to a microcontroller

Using RTC’s have the benefits of

a) A real-time clock ensures the continuous and accurate tracking of time even during system disruptions like hangs, sleeps, or reboots, and can maintain time without requiring reconfiguration, especially with adequate backup power.

b) It operates with low power consumption, which is crucial when running on alternative power sources.

c) By handling time-related functions independently, it allows the main system to focus on critical tasks.

d) In some cases, real-time clocks offer superior accuracy compared to alternative timekeeping methods.

Figure 2.6: Image of the 1302 Real-time clock

2. ATmega328P microcontroller

The ATmega328 is an 8-bit Advanced Virtual RISC (AVR) microcontroller with 32KB of internal flash memory. It also includes 1KB of Electrically Erasable Programmable Read-Only Memory (EEPROM), allowing it to retain data even when power is disconnected and resume operations upon reconnection. Additionally, the ATmega328 features 2KB of Static Random Access Memory (SRAM). Its key attributes, such as advanced RISC architecture, efficient performance, low power consumption, a real-time counter with a separate oscillator, 6 PWM pins, programmable Serial USART, software security through programming lock, and a throughput of up to 20 MIPS, make it well-suited for various applications, including this proposed project.

Figure 2.7: ATmega 328P microcontroller

3. Current sensor

The ACS712 Current Sensor is a device used to measure current in a circuit accurately without impacting system performance. It operates based on Hall-effect technology, providing a linear output proportional to the current passing through a conductor. This sensor offers a high level of voltage isolation, low resistance, and precise current measurement capabilities. Current sensing can be achieved through direct methods, using Ohm's law to measure voltage drop, or indirect methods, where the magnetic field generated by the current is detected. The ACS712 utilizes indirect sensing, employing a Hall sensor circuit to detect the magnetic field generated by the current passing through a copper conduction path on the IC. This sensor is capable of providing accurate current measurements and is suitable for applications requiring electrical isolation, as it features built-in isolation between the conduction path and the IC leads.

Operating at a 5V supply voltage, the ACS712 produces an output voltage proportional to the AC or DC current passing through it, with minimal magnetic hysteresis.

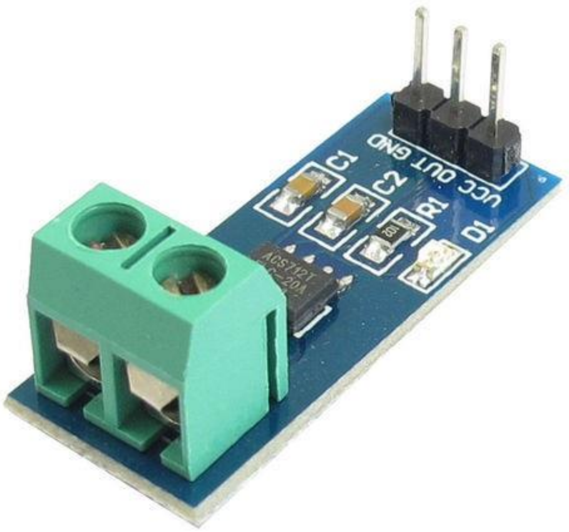


Figure 2.8: ACS712 Current Sensor

4. LCD screen

The LM016L LCD screen is a display unit with a 16x2 configuration, featuring two rows of 16 characters each. It includes an LED backlight for visibility in low-light conditions. Unlike traditional screens that require multiple parallel data lines for control, this screen is designed with integrated circuitry that enables screen control using the I2C protocol, reducing the data lines needed to just two for efficient screen management. The LCD screen is used to show various information related to energy usage, system status and settings. Information to be displayed include:

a. **Energy Consumption**: Real-time data on energy consumption for the entire home or specific appliances. This can help homeowners track their usage patterns and identify opportunities for energy savings.

b. **Battery Status**: The screen displays information about the battery's current charge level, capacity, and whether it's charging or discharging.

c. **System Settings**: Access to settings and controls for the energy management system, allowing homeowners to adjust parameters such as temperature thresholds, charging schedules, and energy-saving modes.

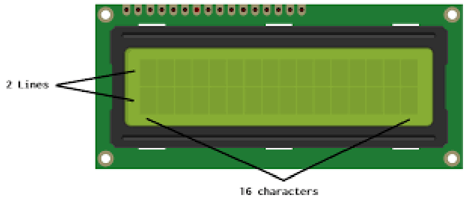


Figure 2.9:16x2 LCD Display

5. Relay module

A relay functions as an electromechanical switch, similar to a manual switch used to open or close a circuit. However, unlike manual switches, a relay operates using an electrical signal to control an electromagnet that connects or disconnects two circuits. Typically, a 5V relay module consists of a coil and two contacts known as normally open (NO) and normally closed (NC).

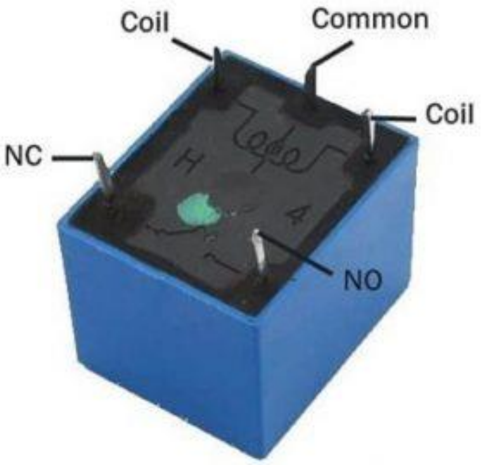


Figure 2.10: Mechanical Relay

6. I2C LCD module

The I2C LCD module provides a convenient and efficient way to interface with common LCD displays (16x2, 16x4, and 20x4) using the I2C protocol. This module simplifies the control of these displays by reducing the number of I/O pins required. With 8 possible addresses (0x20 to 0x27), up to 8 of these interface modules can be controlled simultaneously using only 2 connections. The built-in potentiometer on the module allows for easy adjustment of the LCD's backlight and contrast.

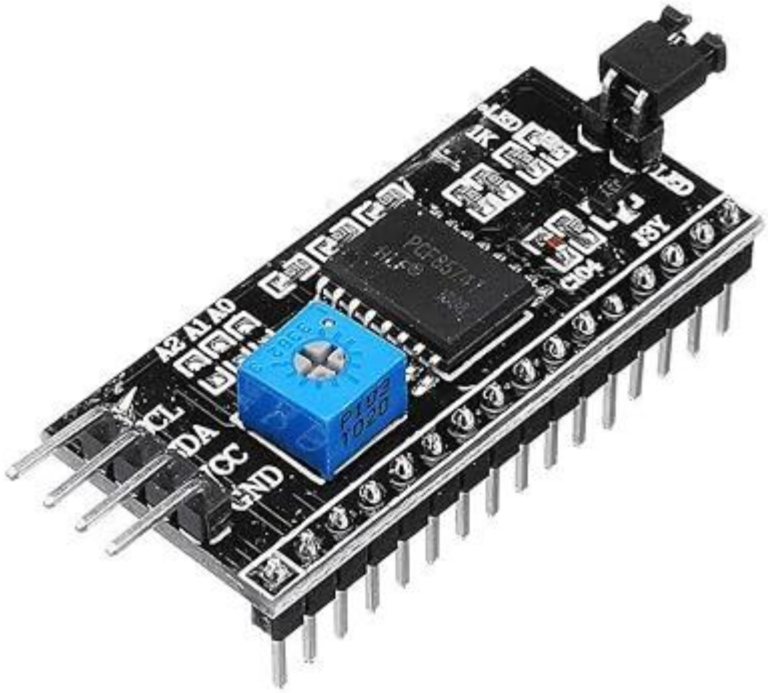


Figure 2.11:I2C LCD module

7. DC-DC buck converter

A DC-to-DC converter known as a buck converter or step-down converter lowers voltage while raising current flows from the source to the load. It is a type of switched-mode supply.

Compared to linear regulators, which are less complex circuits that release energy as heat but do not increase output current, switching converters (such as buck converters) offer significantly higher power efficiency as DC-to-DC converters. Battery life is increased and heat production is decreased by the buck converter's effective power conversion. Therefore, it is primarily favored for the manufacture of tiny devices. It is frequently utilized in switched-mode power supplies, or SMPSs, when the needed output DC voltage is lower than the input DC voltage.

Figure 2.12: DC-DC buck converter

8. Transistor IC-ULN2003

The ULN2003A, manufactured by Texas Instruments, is an IC that comprises a set of seven NPN Darlington transistors with a 500 mA, 50 V output capacity. It includes common-cathode flyback diodes designed for switching inductive loads.

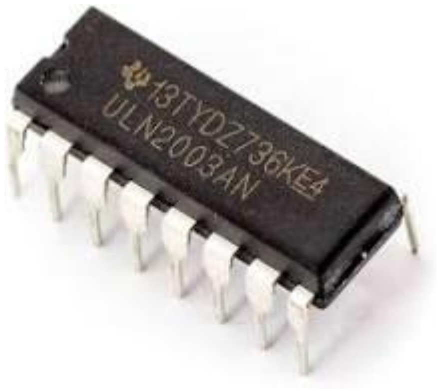


Figure 2.13:ULN2003 Transistor IC

Review of Related Works

Belvedere et al. propose a microcontroller-based power management system (PMS) for standalone microgrids with a hybrid power supply consisting of a fuel cell, battery storage, and photovoltaic emulator (Belvedere et al., 2012). The PMS aims to regulate the fuel cell's power output to maintain the battery's state of charge within a safe range and prevent voltage limit violations. They achieve this by estimating the battery's state of charge based on current and temperature measurements. The control strategy also incorporates protection functions. The PMS was implemented on a microcontroller and tested under various load profiles and initial battery charge levels. Results confirmed the PMS's effectiveness in managing the fuel cell output and maintaining the battery's state of charge during standalone operation. This suggests that a microcontroller-based PMS is a viable solution for managing standalone microgrids with hybrid power sources.

Michaelson, Mahmood, and Jiang (2023) designed a system to improve the service continuity of an isolated microgrid powered by solar panels and batteries (Michaelson et al., 2013). Their objective was to develop a predictive power management strategy. Their strategy utilizes forecasts of solar energy generation and anticipated load to predict future battery charge and potential outages. The methodology also incorporates a pre-emptive load-shedding mechanism to postpone or avoid outages entirely. The results confirm that the proposed strategy, combining predictive forecasting and planned load shedding, is effective in enhancing service continuity within an islanded microgrid.

(Syed & Raahemifar, 2016) proposes a Predictive Energy Management and Control System (PEMCS) for Photovoltaic (PV) systems connected to a weak power grid with periodic load shedding (LS). PEMCS utilizes 24-hour forecasts of various factors to optimize energy usage and minimize renewable energy waste. The system prioritizes local consumption of PV energy, reduces reliance on the grid, and ensures sufficient energy reserves during LS periods. The study concludes that PEMCS is an effective method for improving energy management in PV+BESS systems, leading to a more reliable, efficient, and sustainable power grid.

(Alassi & Ellabban, 2019) proposes an EMS for off-grid renewable energy systems. The system prioritizes stable voltage and critical load supply during varying conditions. The authors achieve this through MPPT control for solar power, PI control for battery management, and a staged load shedding/restoration strategy. Simulations validated that the EMS effectively maintains voltage, extends critical load duration, and ensures component protection.

In their paper, they designed and implemented an automation-based load prioritization technique in the residential sector to manage electricity consumption effectively. The authors classify the loads into two categories flexible and non-flexible loads. Non-flexible loads can be regarded as the loads with the highest priority and their scheduled operation time is not adjusted; flexible loads can be regarded as loads with the lowest priority and their time of operation can be readily shifted to reduce energy consumption. The ATmega 2560 microcontroller is the core of the design. The suggested method organizes the loads in order of usage and user comfort. The outcome demonstrates that by automatically reducing load based on a priority mechanism, the suggested solution can effectively reduce the amount of work that a man must perform.

2.7 Block Diagram

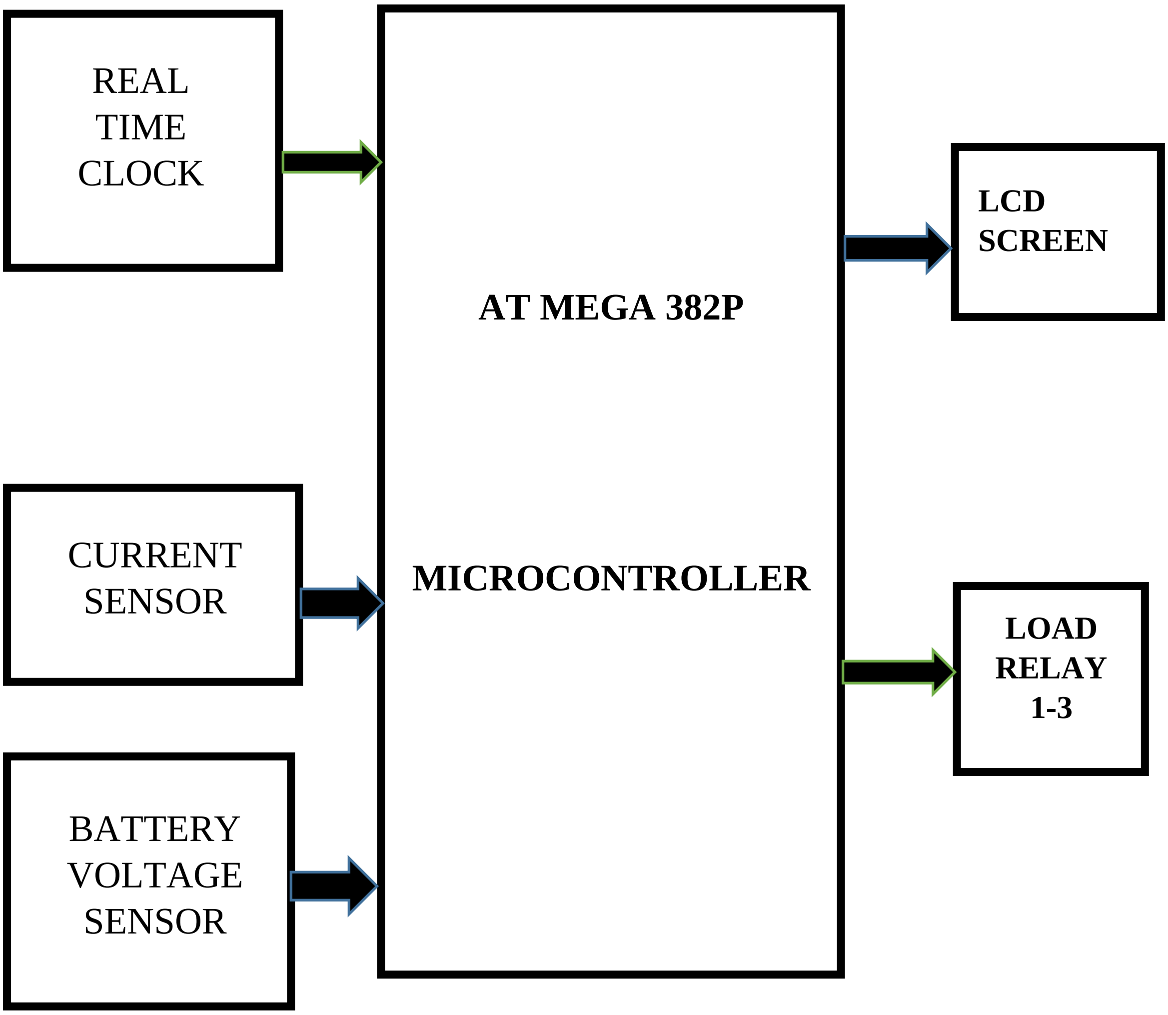


Figure 2.14: System Block Diagram

CHAPTER THREE - DESIGN AND ANALYSIS

3.1.1 Microcontroller Unit (ATMEGA 328P)

The microcontroller chosen is ATMEGA328P. It has a variety of properties which makes it efficient for the system.

ATMEGA 328P is an 8-bit AVR Microcontroller with 32K Bytes In-System Programmable Flash. It is a low power CMOS that executes powerful instructions in a single clock cycle.

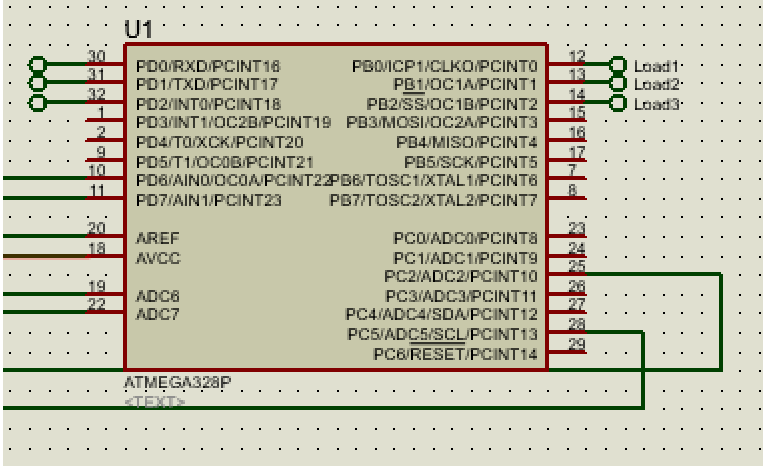


Figure 3.1 ATmega 328P

By achieving throughputs before it reaches 1MIPS per MHZ, it allows the system designer to optimize power consumption and processing speed.

This microcontroller consists of a CPU core, Arithmetic and Logic Unit (ALU), a status register, an AVR status register (SREG), file register and stack pointer.

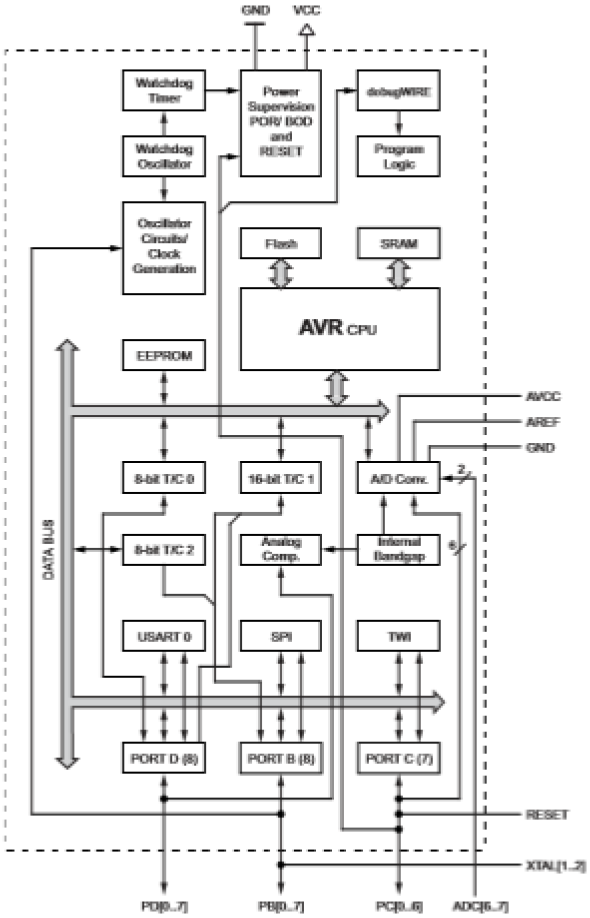


Figure 3.2 ATmega 328p Architecture

3.1.2 A Display Unit (LM016l)

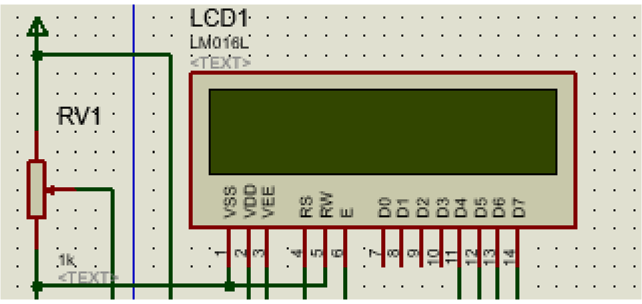


Figure 3.3 Lcd Display Screen

The Display Unit consists of an LCD (Liquid Crystal Display) Screen.

The chosen LCD screen is LM016L. It is a 16X2 display screen which shows the status of the system. It was chosen because of its effectiveness when displaying system information- 16 characters in two rows.

3.1.3 Current Sensing Unit (ACS 712)

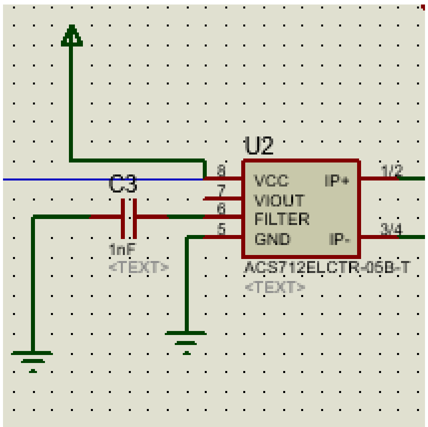


Figure 3.4 Current Sensor (ACS 712)

Current sensing is a major way of determining the

amount of current in a system. For this system, the chosen current sensor is ACS 712.

Chosen because of easy implementation by the consumer and its capacity to provide economical and accurate results for alternating or direct current sensing, this sensor has applications such as motor control, load detection and management, peak detection circuit amongst others.

The ACS712 can work with an Arduino and it operates with a two directional hall effect current sensor chip.

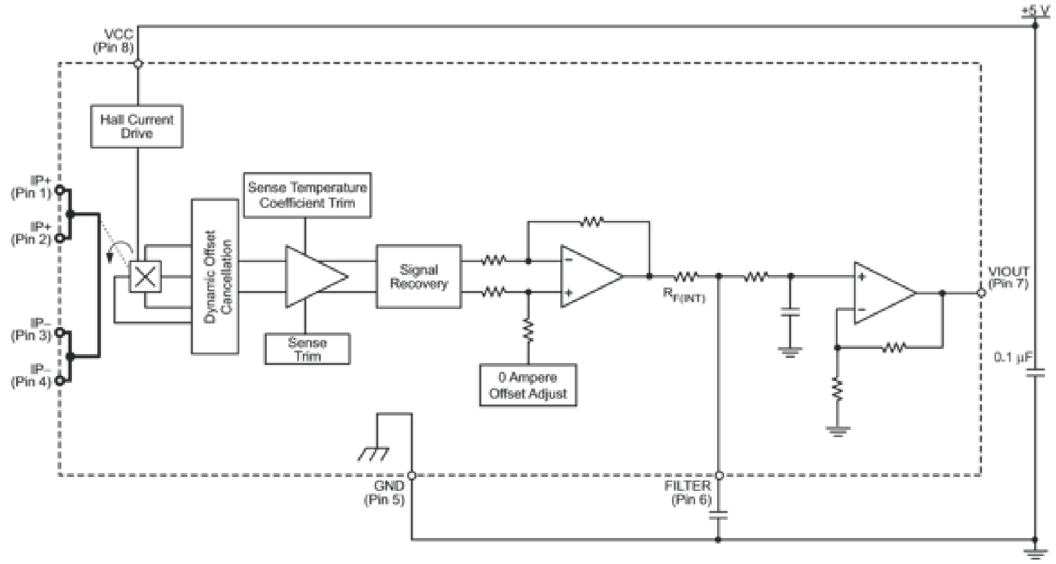


Figure 3.5 Functional Block Diagram of ACS712

3.1.4 Load Relay Unit

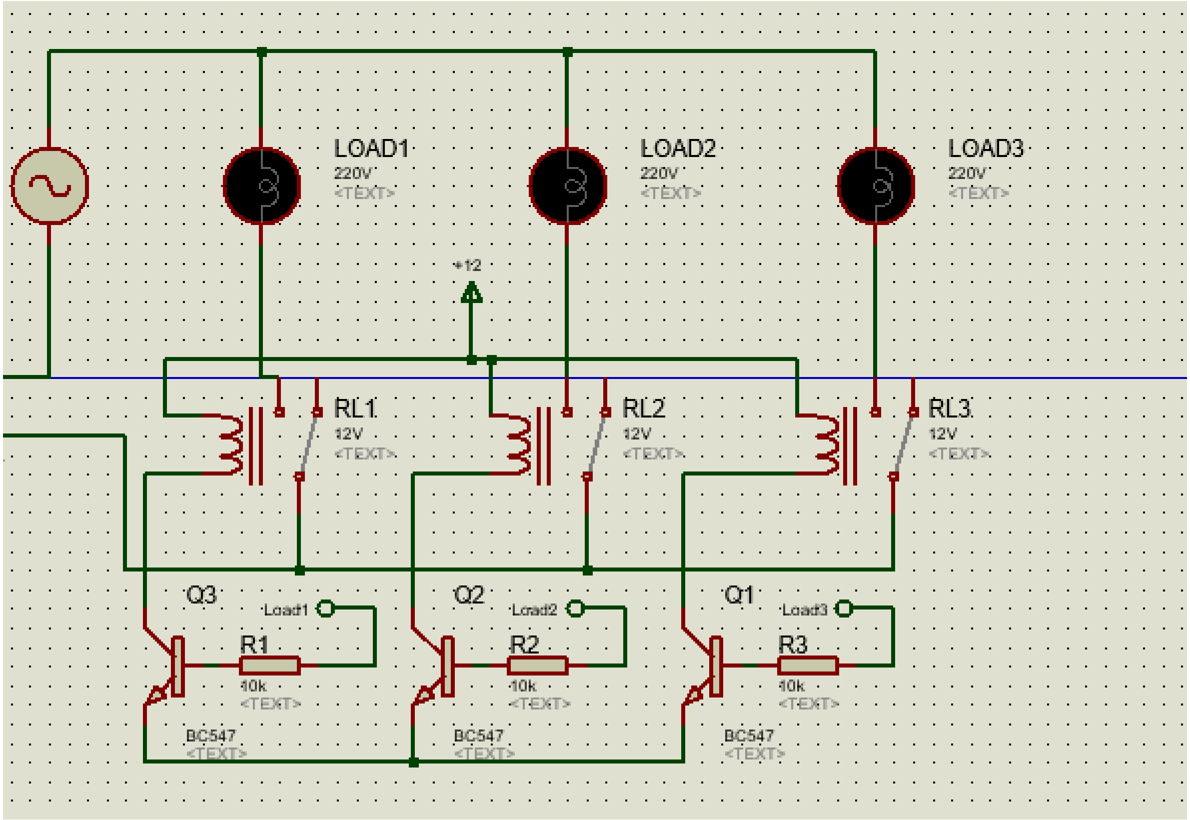


Figure 3.6 Load Relay

This block comprises of a transistor, relays, load and its accompanying circuitry which enables the microcontroller to effectively control the output supply to the load. The circuit diagram of this block is shown ABOVE.

The load relay is the safety component in the system that protects the circuit from damage caused by high power loads.

In this case, three loads were connected across the circuit.

3.1.5 Battery Voltage Sensor Unit

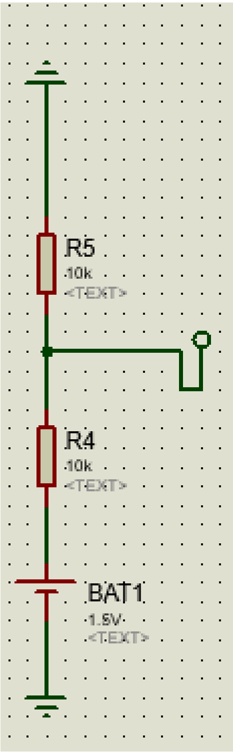


Figure 3.7 Battery Voltage Sensor

The voltage sensor unit consists of a 2.5v battery connected to two resistors of known resistance 10 kilo ohms. Both the end terminals of the resistors and battery are connected to ground.

3.2 Design Considerations

The following considerations and assumptions were made in designing the system.

1. In designing the system, the ATMEGA 382P was preferred over other microcontrollers because of its code effectiveness over other microcontrollers in achieving throughputs which can be ten times faster than other conventional microcontrollers.
2. In the prototype designed on Proteus, three loads were connected across the system.
3. A D.C Buck converter module is used as the power source.

3.3 Design Components

The different components assembled together to give the system are stated below.

1. Power Source- D.C Buck voltage converter
2. Battery voltage sensor
3. Microcontroller (ATMEGA 382P)
4. Crystal Oscillator
5. Relay
6. LCD Screen
7. Transistor

3.3.1 Power Supply

The power supply is a D.C Buck Voltage Converter. It is a DC-to-DC converter which decreases voltage while increasing current from its input to its output (load).

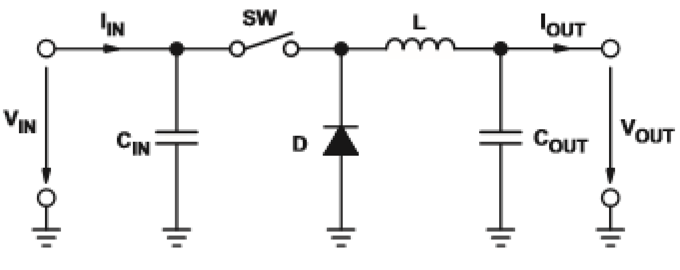


Figure 3.8 Buck Converter Power Stage

3.3.1.1 Relevant Parameters in Calculating The Maximum Switch Current And Power Stage For The Dc Buck Converter

The following parameters are necessary in the calculation the power stage:

1. Input Voltage Range
2. Nominal Output Voltage (V_{OUT})
3. Maximum Output Current $(I_{OUT})_{MAX}$
4. Integrated Circuit used to build the buck converter.

3.3.1.2 Maximum Switch Current

1. The first step is to calculate the maximum duty circle.

Maximum Duty Circle,

$$D = \frac{V_{OUT}}{V_{IN(max)}} \times \eta \ldots\ldots\ldots.\ldots\ldots(1)$$

NOTE: n represents the efficiency of the converter

$V_{IN\ (max)}$ represents the maximum input voltage

2. The second step is to calculate the Inductor Ripple Current

$$= \left(V_{IN(max)} - V_{OUT}\right) \times \frac{D}{fs} \times L \ \ldots\ldots..(2)$$

Where:

f_s = minimum switching frequency of the converter

L = selected inductor value

D = duty circle calculated in equation 1

From this, the maximum switch current can be gotten if the maximum output current is below the calculated value.

Therefore,

$$Maximum\ Switch\ Current = \frac{\frac{\Delta IL}{2} + I_{OUT(MAX)}}{2}$$

3.3.2 Design of Micro Controller Unit

The micro controller black consists of two 22pF capacitors, a crystal oscillator, all connected to ground.

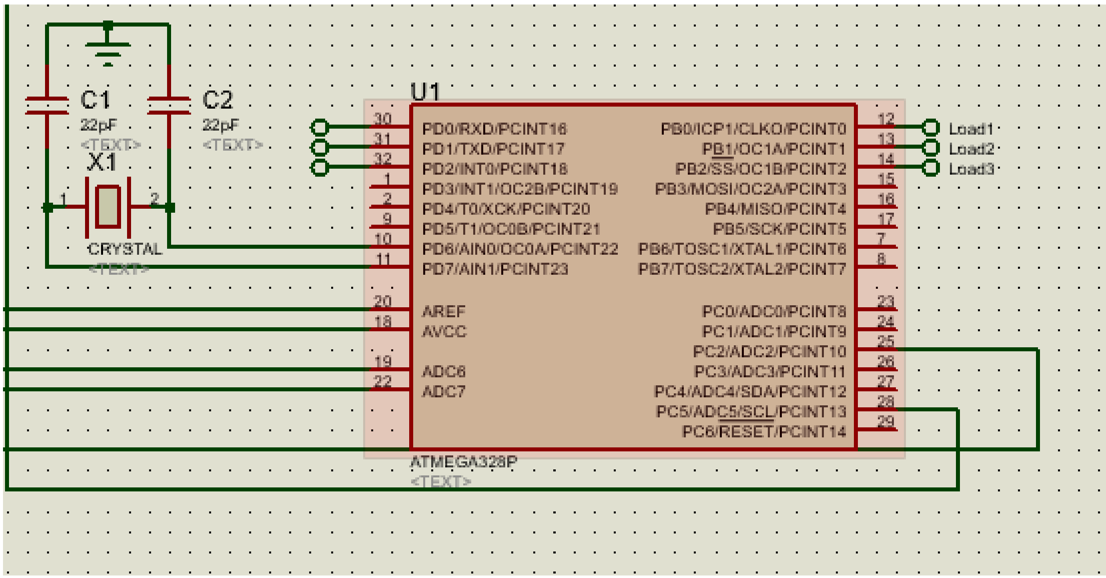


Figure 3.9 Micro Controller with Pin Connections

3.3.2.1 The Crystal Oscillator.

A 16MHZ oscillator was used as recommended by the microcontroller's datasheet. The 16MHZ crystal oscillator was connected to the microcontroller's AIN1 and AIN 0 pins.

$$Micro\ controller's\ instruction\ execution\ speed = \frac{1}{frequency} \times 4\ cycles$$

At a frequency of 16MHZ, the execution speed of the microcontroller can be calculated as;

$$\frac{1}{16000000} \times 4\, cycles \ = 64\text{µs}$$

Also,

we can calculate the value of the capacitors connected across the 16MHZ crystal by applying the formula:

$$C_L = \frac{1}{\left(\frac{1}{C2} + \frac{1}{C3}\right)} + \ C_{parasitic}$$

Where $C_2 = C_3 = C$

$$C_L = \ \frac{1}{\frac{1}{C} + \frac{1}{C}} + C_{parasitic}$$

C $_{\text{parasitic}}$ = 0

C_L = Loading capacitor= 8pf

$$C_L = \frac{1}{\frac{1}{C} + \frac{1}{C}} + \ 0$$

C = 2 × $C_{L;}$ C = 2 × 8pF = 16pF

A 16pF capacitor was available and was used in the design of the microcontroller unit.

3.3.3 Connections or Design of The LCD Unit

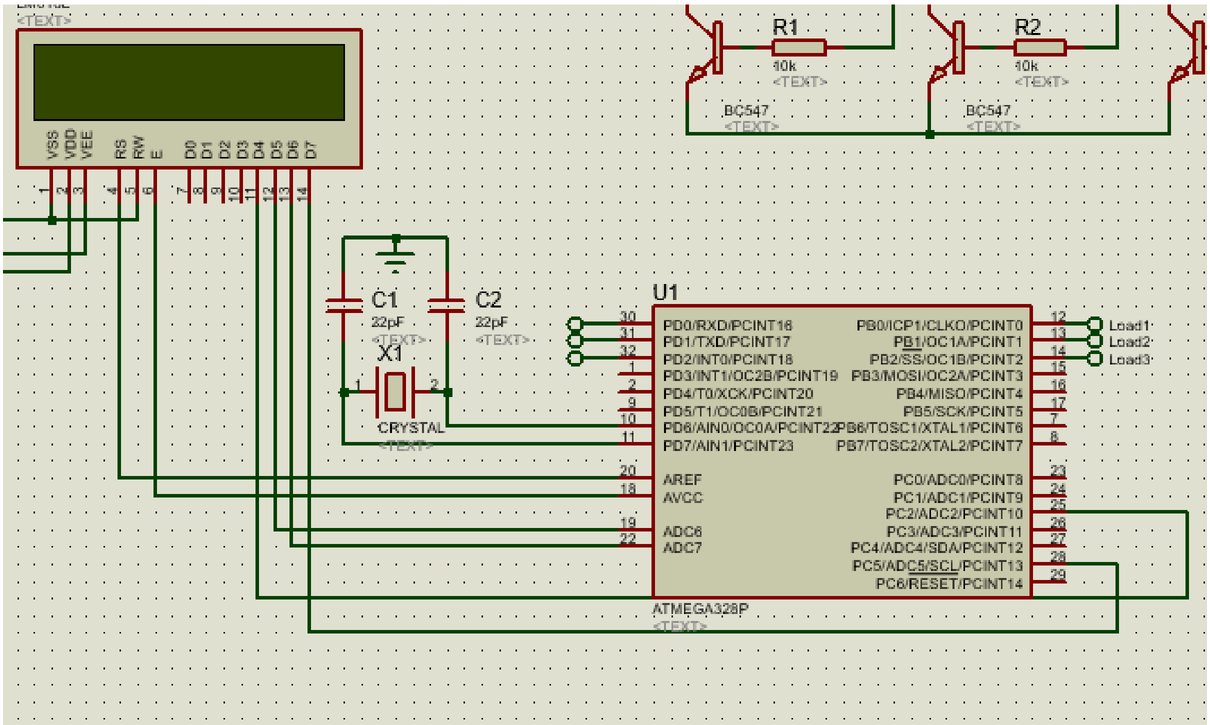


Figure 3.10 LCD CONNECTIONS TO ATMEGA 328P

The following connections were made:

RESET (RS) pin is connected to pin 20 of the microcontroller (AREF).

ENABLE (E) is connected to pin 18 of the micro controller (AVCC).

DATA PIN 4 (D4) is connected to pin 25 of the microcontroller.

DATA PIN 5 (D5) is connected to pin 19 of the microcontroller.

DATA PIN 6 (D6) is connected to pin 22 of the microcontroller.

DATA PIN 7 (D7) is connected to pin 28 of the micro controller.

VSS PIN is connected to one of the two end terminals of a 1k resistor and then connected to the ground.

3.3.4 Bi-Polar Junction Transistor (BC547)

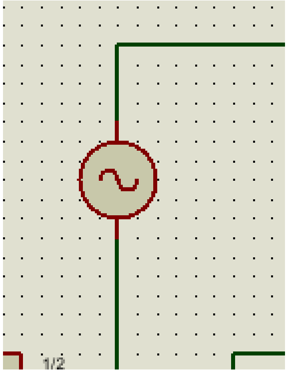


Figure 3.11 The BC 547

As seen in figure 4.0 above, a BC547 bipolar junction transistor (BJT) is used in this circuit, this transistor has the following key features.

i. It is an NPN transistor

ii. The gain of DC current (hFE) is 8

iii. The continuous collector current I_C is 100mA

iv. Emitter Base voltage (VBE) is 6V

v. The maximum switching frequency is 300Hz

vi. Power dissipation is 625mW

3.3.4.1 Transistor Base Resistor Calculations

The formula for calculating the base resistor of the transistor is given by the expression:

$$R = \frac{(U_s - 0.6)hFE}{Relay\ Coil\ Current} - - - - - - - - \ (3.7)$$

Where

R = base resistor of the transistor as seen in figure 3.6 above.

Us = Source or the trigger voltage to the base resistor,

hFE = Forward current gain of the transistor, The last expression which is the "relay current" may be found out by solving the following Ohm's law:

$$I = \frac{V_s}{R} ----------------(3.8)$$

Where

I = the required relay current

V_S = Supply voltage to the relay.

Given that the relay used is a 5V relay with a relay coil resistance of 500Ohms, hFE of the BC547 transistor is 8 the relay current I can be calculated as follows

$I = \frac{5}{400} = 0.0125A$

Applying the above values to equation 3.7 we get,

$$R = \frac{(5 - 0.6)8}{0.0125} -----------(3.9)$$

R = 2816Ohms, R ≈ 3KOhms

3.4 Complete Circuit Diagram

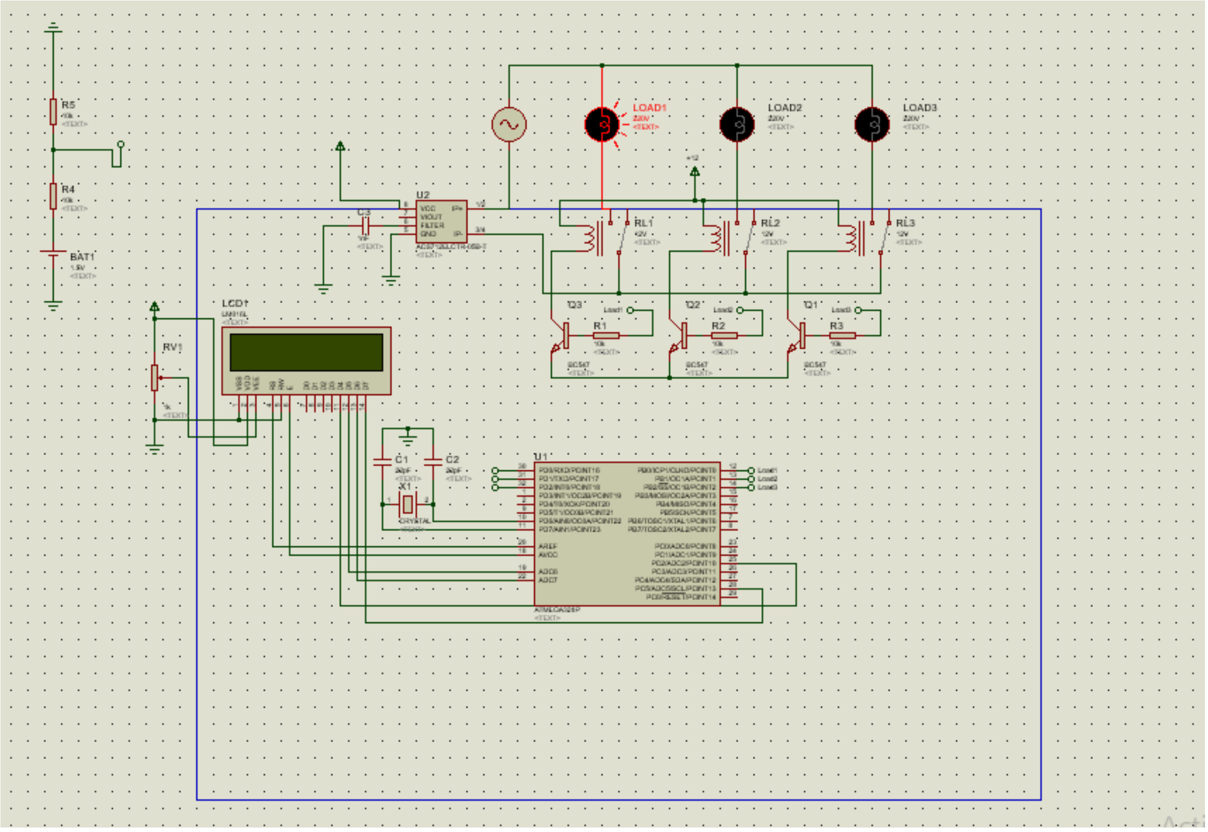


Figure 3.12 COMPLETE CIRCUIT DIAGRAM

3.5 System Flowchart

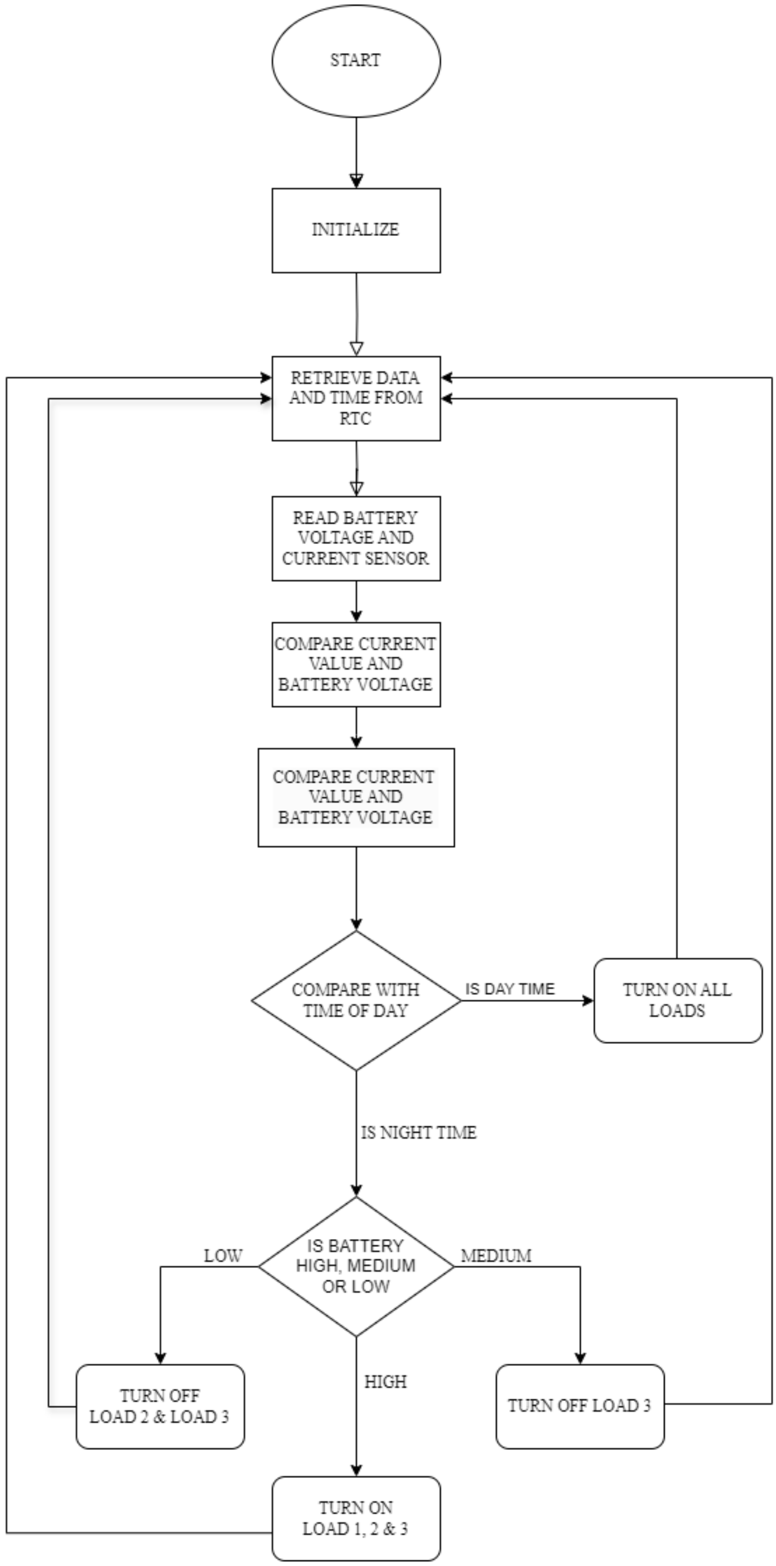


Figure 3.13 Flowchart of the System

3.6 Working Principle of The System

When the device is powered up the microcontroller receives power and executes the code inside the system. The microcontroller then confirms communication with the real-time clock and extracts the time and date data that has been saved into it. Once the data is extracted it is displayed on the liquid crystal display (LCD) briefly and then the microcontroller monitors the status of the load present in the house. Before switching takes place, the microcontroller confirms the battery voltage of the solar system.

The microcontroller adjusts the load used in the building based on battery voltage and time of day. The microcontroller compares the time of day with battery voltage to determine which load is to be turned off or which load is to be made available. When the battery voltage is high enough or within the range of time allocated for the different loads. When the solar power is at its peak (probably in the afternoon), it allows for maximum load usage in all tiers (all loads turn on), when the sun power is low or battery voltage has reduced to half, heavy loads (air conditioners, fridges) will be turned off automatically while in the night or when the battery voltage is very low, average loads are turned off (fans, television). To achieve this, the microcontroller sends a signal to the transistor unit which the transistor uses to switch on the relay corresponding to the load which will be available to the user.

For the relays, three relays were used corresponding to three load types; basic load (light bulbs, charging ports), intermediate loads (fans, television), and heavy loads (air conditioners, fridges).

The real-time clock has a backup battery system that ensures the time runs continuously even when there is a power outage and there is also a system there ensures the battery remains charged when there is power source.

The LCD screen displays the load current and which load is turned on. It also displays the time and date. The user can connect to the output terminals to decide which load will be on accordingly.

CHAPTER FOUR - CONSTRUCTION, TESTING AND RESULTS

4.1 Construction

After compiling the code and successful simulation, the next process is the building of the hardware.

This was not entirely an easy process as it included different sections such as the purchase of components such as resistors, Vero board, and LCD screen which were not entirely readily available.

Soldering of different components on the Vero board was next. The Vero board served as the base for mounting other components.

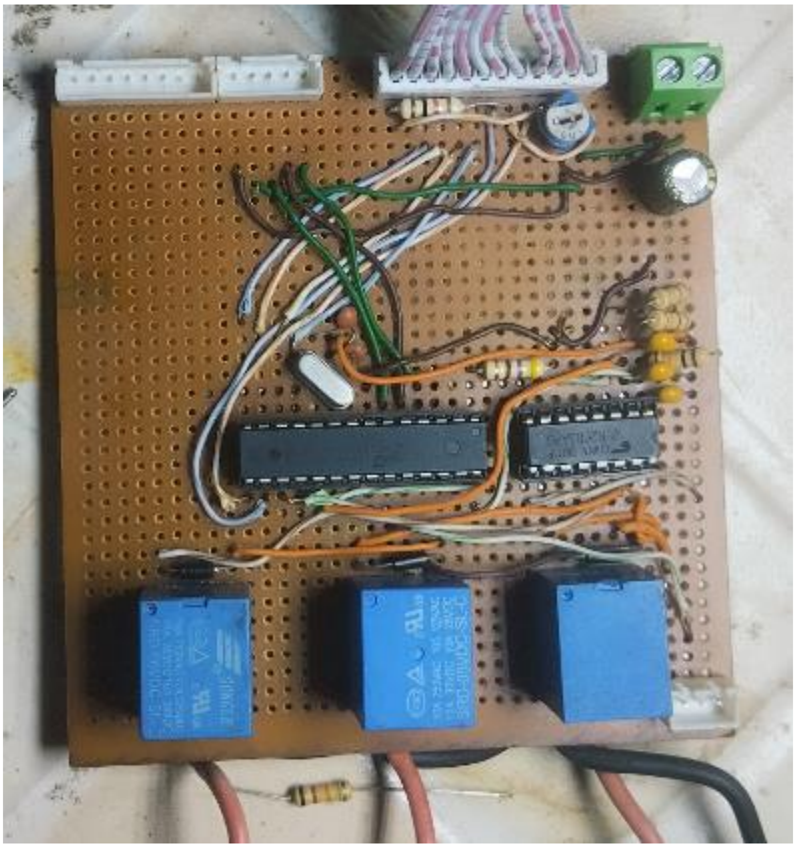
This had to be done carefully and firmly to ensure no two components were bridged. The program was then loaded into the microcontroller and the casing followed.

The process of construction is as follows;

- A continuous Vero board was chosen.
- Circuit is built on Proteus to serve as a guide.
- Components are soldered correctly following their right electric paths on the Vero board.
- The working of the LCD was tested by transferring code to a programmer and then connecting to the LCD using a USB cord to the right port on the laptop. LCD screen came on, showing the date and time.
- The circuit undergoes several tests for continuity, voltage and load. A multi-meter was used for the continuity test. This test is very important as it shows where isolation is required, as a result of bridging which can destroy electronic components.

4.2 Mounting and Soldering of Components

Components are mounted and soldered on the Vero board in accordance with the Proteus Design.



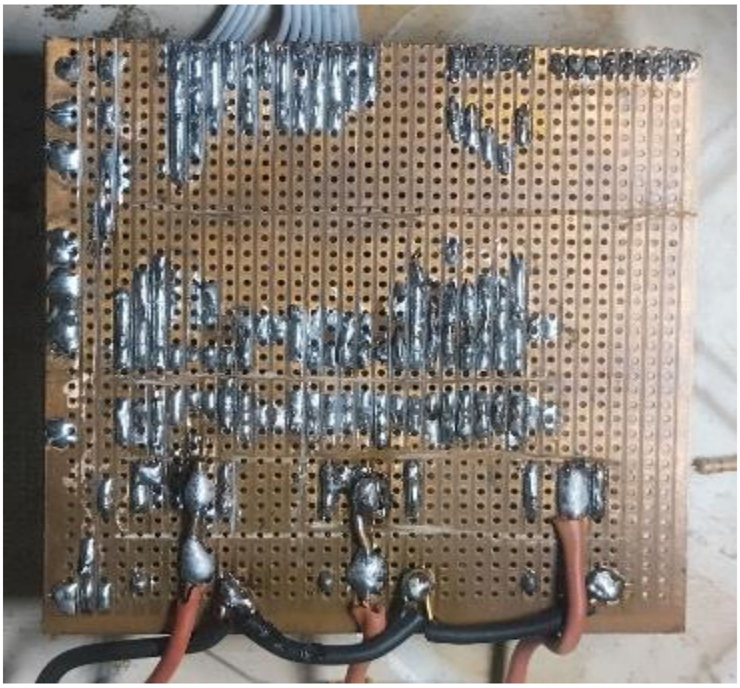
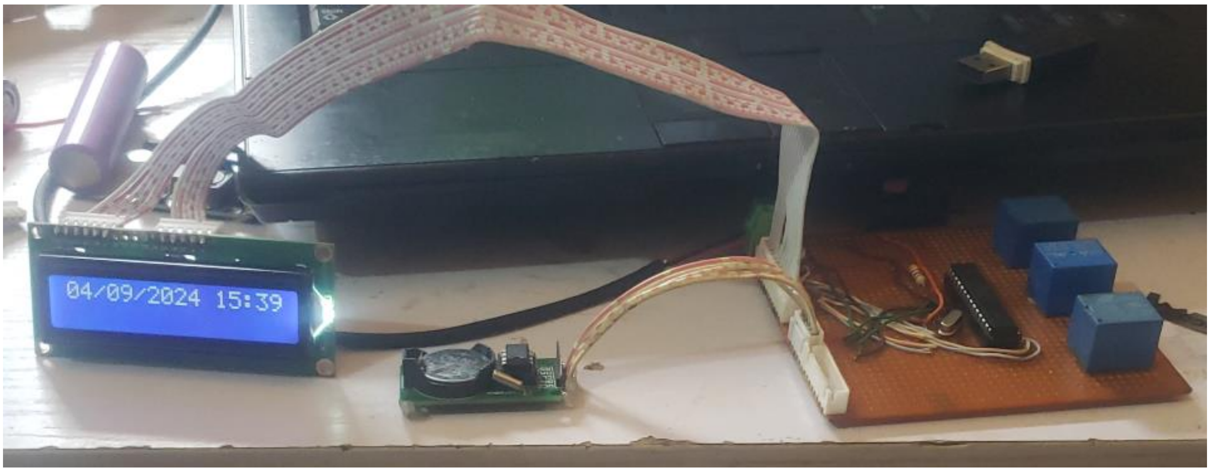


Figure 4.1:Mounting and Soldering of Components on Vero Board



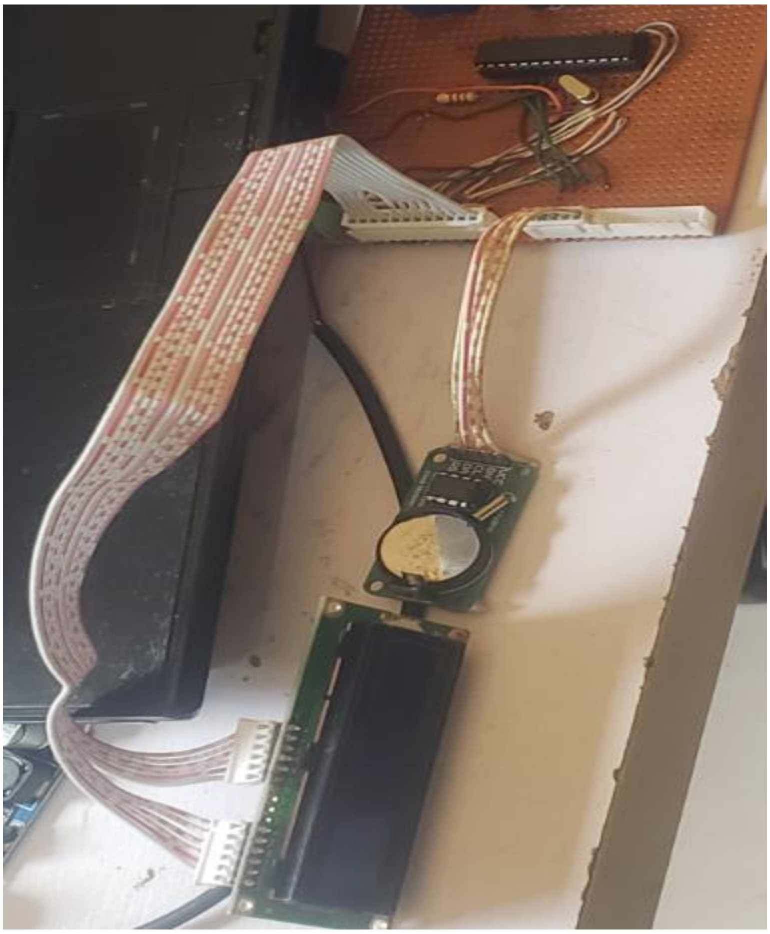


Figure 4.2:Circuit Coupling

4.3 Casting Layout and Dimension

The device is packaged in a plastic case of dimension 22.5cm × 15cm.

A cut is made on the surface to give room for the LCD screen with the dimension of 7.1cm×2.1cm

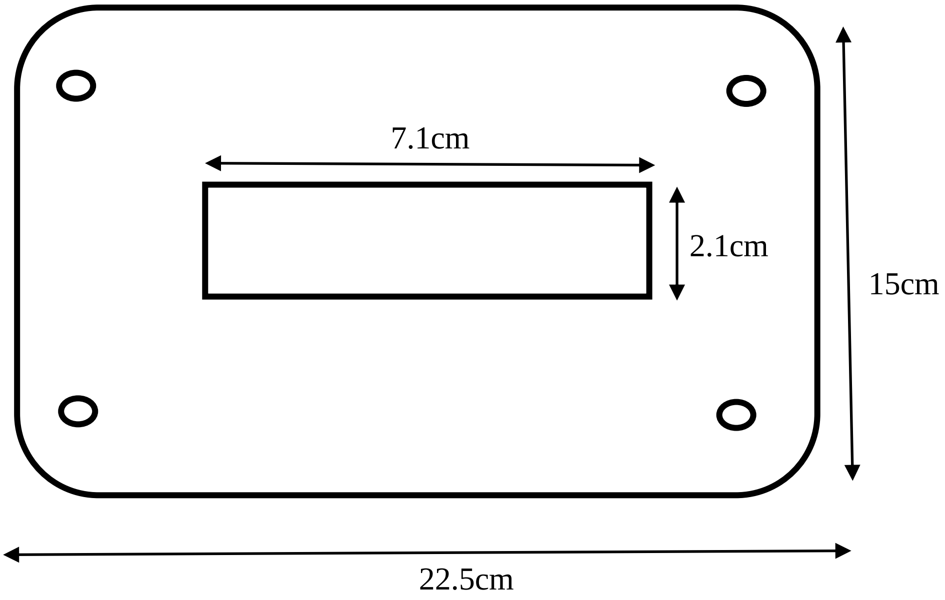


Figure 4.3:Front View Dimension

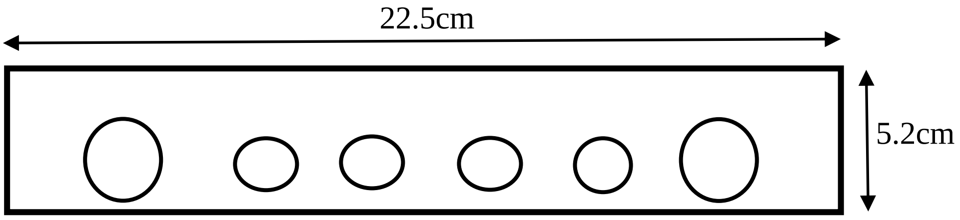


Figure 4.4:Side View Dimension

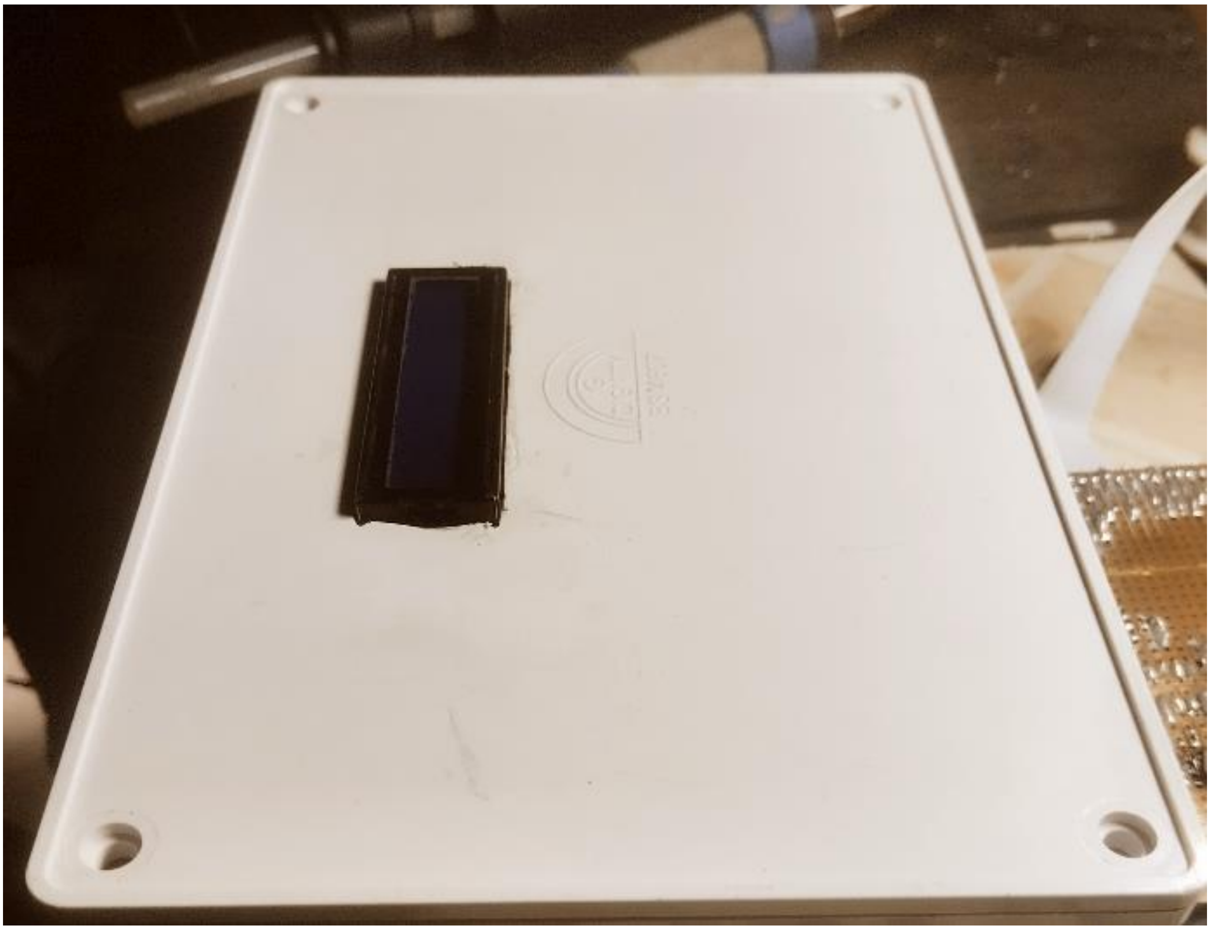


Figure 4.5:Pictorial Front View

Figure 4.6:Pictorial Side View

4.4 Testing

As earlier stated, three tests were carried out on the system which are continuity test, voltage test and load test.

Continuity test done in other to determine the damaged components in a circuit. It is also a determining factor in the quality of soldering done. It is mostly done with the help of a multimeter. This is because the resistance of conductors between the two ends is usually very small.

One of the easiest ways to test for voltage is to use a multimeter. Measuring the voltage of a component on the circuit board entails connecting the probes of the multimeter to the terminals of the component. Red indicates a positive terminal while black indicates a negative terminal.

The load test has its relevance which is to measure response time, rates of throughputs, and identification of device or application breaking points. It identifies the system's breaking point by measuring the speed or capacity of the system.

With this, it can determine a system’s performance under real-life load conditions.

4.5 Results

From the stated tests and observations obtained after subjecting the system to real-life load conditions, it has been concluded that the system acted in accordance with its intended design which is to optimize solar power utilization by intelligent load management.

It can be stated that the system passed all tests and can be applied for the purpose it was created as it ensures safety and is highly efficient.

Table 4.1 Test results showing battery open circuit voltage (estimated available capacity) before load optimization

SN	TIME (in mins)	BATTERY VOLTAGE (Volt)

1.	20	26.65
2.	220	26.55
3.	420	26.45
4.	620	26.34
5.	820	26.14
6.	1020	25.94
7.	1220	25.72
8.	1420	25.32
9.	1620	24.92
10.	1640	24.88
11.	2000	24.06
12.	2200	23.56
13.	2400	23.06
14.	2600	22.56
15.	2800	22.06
16.	3000	21.56
17.	3200	21.06
18.	3400	20.56
19.	3580	20.11
20.	3600	20.06

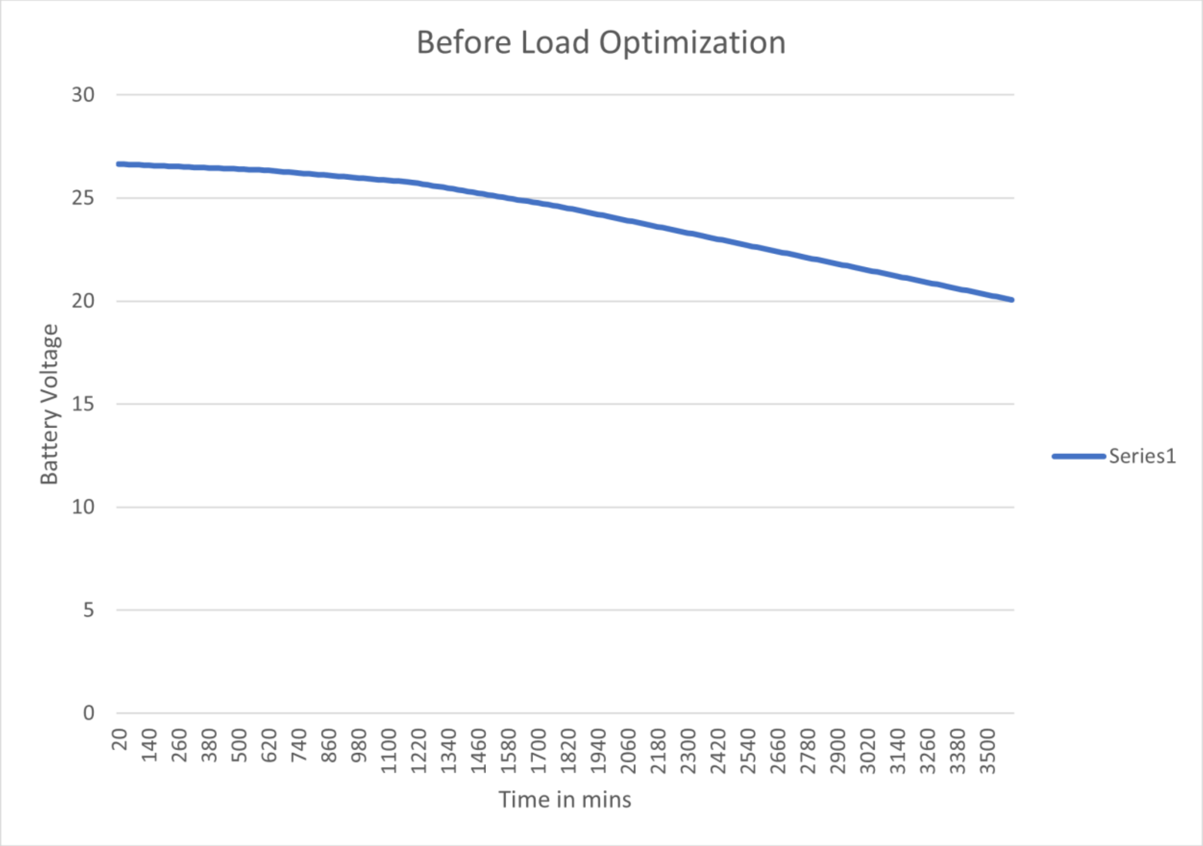


Figure 4.7 Chart showing battery available battery capacity at different time intervals before load optimization

Table 4.2 Test results showing battery open circuit voltage (estimated available capacity) after load optimization

SN	TIME (in mins)	BATTERY VOLTAGE
1.	20	26.65
2.	220	26.56
3.	420	26.46
4.	820	26.15
5.	1020	25.95
6.	1220	25.75
7.	1420	25.55
8.	1620	25.35
9.	1820	25.15
10.	2020	24.88
11.	2220	24.58
12.	2420	24.28
13.	2620	23.98
14.	2820	23.68
15.	3020	23.38
16.	3220	22.99
17.	3420	22.59
18.	3600	22.23

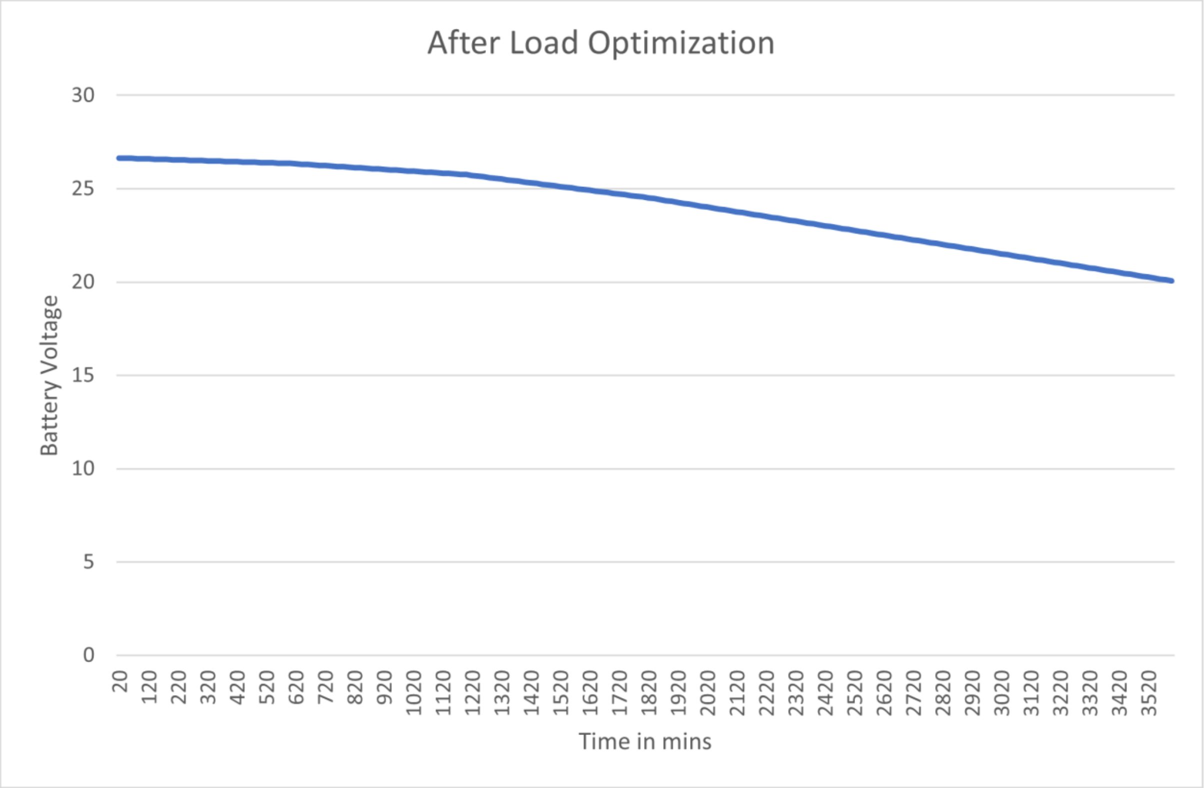


Figure 4.8 Chart showing battery available battery capacity at different time intervals after load optimization

4.6 Bill of Engineering Measurement and Evaluation

Table 4.3 Evaluated Bill

Item	Amount	Unit	Price per Unit (N)	Total Cost (N)
Current Sensor	3	Pieces	1000	3000
Current Transformer	3	Pieces	1000	3000
Voltage Sensor	1	Piece	1000	1000
Real-Time Clock	1	Piece	1500	1500
Arduino-Uno	1	Piece	15000	15000
LCD Screen	1	Piece	3000	3000
Relay Module	1	Piece	3000	3000

Vero board	2	Pieces	1500	3000
I^2C LCD Module	1	Piece	1500	1500
Terminal	5	Pieces	200	1000
Arduino Holder	1	Piece	1500	1500
Power Switch	1	Piece	1000	1000
DC-DC buck converter	1	Piece	2000	2000
Led	5	Pieces	200	1000
Masking Tape	1	Piece	500	500
PVC Box	1	Piece	3000	3000
Cables, wires, and jumpers	100, 50	Yards, pieces	200	3500
Diodes	8	Pieces	100	800
Capacitors	10	Pieces	10	100
Transistor IC	2	Piece	1000	1000
Resistors	20	Pieces	20	200
Wire Pegs	5	Pieces	100	500
Bolt and Screws	5	Pieces	50	1000
Glue Gun Sticks	2	Pieces	300	600
SUM TOTAL	-	-	-	51,700

CHAPTER FIVE - CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

A microcontroller-based controller that optimizes solar power consumption by strategically carrying out the shedding of selected loads based on the time of day and available battery capacity has been designed and implemented. It works by categorizing the loads into three tiers based on user preference, load power consumption and criticality of the loads. when the panels are generating enough power in daytime to recharge the batteries, load shedding is not carried out and all the three load classes are powered on. At night time, load shedding takes place based on available battery capacity. The overall system design is compact, efficient, and of low cost as it was designed for use by low-income households, to improve system reliability and availability by reducing the number of storage systems required for the system to operate for a given period of time.

5.2 Limitations

The main drawbacks of the developed system include the following:

a. The device does not take the comfort and preference of the user into consideration.
b. The loads and the order which it carries out the load shedding may not be optimal because of the use of a rule-based algorithm and hence, while load shedding is being carried out, the reduction in power consumption be low.
c. As prevailing weather conditions is not considered, because time of day and not available solar radiation is used as criteria for load shedding, all loads may be powered on while the battery is not charging thereby affecting system reliability.
d. The voltage-based method for calculating battery capacity is limited and does not consider battery state of health, hence, overtime as available battery capacity reduces, the system reliability is also severely affected.

5.3 Recommendations

After the completion of the project work, the following recommendations are made in order to achieve a more efficient system;

a. Prevailing weather conditions should be considered while making decisions for load shedding.
b. The method of analysing battery capacity should consider battery state of health.
c. The algorithm used should be able to learn about the user’s behaviour and shed load based on it while also shedding loads optimally.

REFERENCES

Adedeji, I., Deveci, G., Salman, H., Abiola, I., Adedeji, I., Deveci, G., et al. (2023). The Benefits of Solar Energy on the Provision of Sustainable Affordable Housing in Nigeria. *Journal of Power and Energy Engineering*, *11*(6), 1–15. https://doi.org/10.4236/JPEE.2023.116001

Ahmad, A., Khan, A., Javaid, N., Hussain, H. M., Abdul, W., Almogren, A., et al. (2017). An optimized home energy management system with integrated renewable energy and storage resources. *Energies*, *10*(4), 1–35. https://doi.org/10.3390/en10040549

Alassi, A., & Ellabban, O. (2019). Design of an Intelligent Energy Management System for Standalone PV/Battery DC Microgrids. *2nd International Conference on Smart Grid and Renewable Energy, SGRE 2019 - Proceedings*. https://doi.org/10.1109/SGRE46976.2019.9020679

Bamisile, O., Dagbasi, M., Babatunde, A., & Ayodele, O. (2017, October 1). A review of renewable energy potential in Nigeria; Solar power development over the years. *Engineering and Applied Science Research*. Paulus Editora. https://doi.org/10.14456/easr.2017.37

Batista, A. C., & Batista, L. S. (2018). Demand Side Management using a multi-criteria ϵ-constraint based exact approach. *Expert Systems with Applications*, *99*, 180–192. https://doi.org/10.1016/J.ESWA.2018.01.040

Bayram, I. S., & Ustun, T. S. (2017). A survey on behind the meter energy management systems in smart grid. *Renewable and Sustainable Energy Reviews*, *72*, 1208–1232. https://doi.org/10.1016/J.RSER.2016.10.034

Beaudin, M., & Zareipour, H. (2015). Home energy management systems: A review of modelling and complexity. *Renewable and Sustainable Energy Reviews*, *45*, 318–335. https://doi.org/10.1016/J.RSER.2015.01.046

Belvedere, B., Bianchi, M., Borghetti, A., Nucci, C. A., Paolone, M., & Peretto, A. (2012). A microcontroller-based power management system for standalone microgridswith hybrid power supply. *IEEE Transactions on Sustainable Energy*, *3*(3), 422–431. https://doi.org/10.1109/TSTE.2012.2188654

Bouakkaz, A., Gil, A. J., Haddad, S., & Luigi, M. (2020). Efficient energy scheduling considering cost reduction and energy saving in hybrid energy system with energy storage. *Journal of Energy Storage*, (August), 101887. https://doi.org/10.1016/j.est.2020.101887

Dinh, H. T., Yun, J., Kim, D. M., Lee, K. H., & Kim, D. (2020). A Home Energy Management System with Renewable Energy and Energy Storage Utilizing Main Grid and Electricity Selling. *IEEE Access*, *8*, 49436–49450. https://doi.org/10.1109/ACCESS.2020.2979189

Falope, T., Lao, L., Hanak, D., & Huo, D. (2024). Hybrid energy system integration and management for solar energy: A review. *Energy Conversion and Management: X*, *21*, 100527. https://doi.org/10.1016/J.ECMX.2024.100527

Fleischer, C., Waag, W., Bai, Z., & Sauer, D. U. (2013). Adaptive On-line State-of-available-power Prediction of Lithium-ion Batteries, *13*(4), 516–527.

Galera, K. M. E., & Llantos, O. E. (2017). Mobile Web Energy Monitoring System Using DFRduino Uno. *Procedia Computer Science*, *124*, 706–713. https://doi.org/10.1016/j.procs.2017.12.208

Lashway, C. R., & Mohammed, O. A. (2016). Adaptive battery management and parameter estimation through physics-based modeling and experimental verification. *IEEE Transactions on Transportation Electrification*, *2*(4), 454–464. https://doi.org/10.1109/TTE.2016.2558843

Lavigne, L., Sabatier, J., Francisco, J. M., Guillemard, F., & Noury, A. (2016). Lithium-ion Open Circuit Voltage (OCV) curve modelling and its ageing adjustment. *Journal of Power Sources*, *324*, 694–703. https://doi.org/10.1016/j.jpowsour.2016.05.121

Marwan, M., Naim, K., Thaha, S., Sofyan, S., Idris, A. R., & Asri, A. (2021). Integrating on-site renewable energy to innovative EDRP in reducing electricity peak demand. *ICAICST 2021 - 2021 International Conference on Artificial Intelligence and Computer Science Technology*, 113–117. https://doi.org/10.1109/ICAICST53116.2021.9497827

Michaelson, D., Mahmood, H., & Jiang, J. (2013). A predictive energy management strategy with pre-emptive load shedding for an islanded PV-battery microgrid. *IECON Proceedings (Industrial Electronics Conference)*, 1501–1506. https://doi.org/10.1109/IECON.2013.6699355

Mohammad, A., Zuhaib, M., & Ashraf, I. (2022). An optimal home energy management system with integration of renewable energy and energy storage with home to grid capability. *International Journal of Energy Research*, *46*(6), 8352–8366. https://doi.org/10.1002/ER.7735

Ohunakin, O. S., Adaramola, M. S., Oyewola, O. M., & Fagbenle, R. O. (2014). Solar energy applications and development in Nigeria: Drivers and barriers. *Renewable and Sustainable Energy Reviews*, *32*, 294–301. https://doi.org/10.1016/j.rser.2014.01.014

Rivera-Barrera, J. P., Muñoz-Galeano, N., & Sarmiento-Maldonado, H. O. (2017). *Soc estimation for lithium-ion batteries: Review and future challenges*. *Electronics (Switzerland)* (Vol. 6). https://doi.org/10.3390/electronics6040102

Saka, A. B., Olawumi, T. O., & Omoboye, A. J. (2017). Solar Photovoltaic System: A Case Study of Akure, Nigeria. *World Scientific News*. Retrieved from www.worldscientificnews.com

Shakeri, M., Shayestegan, M., Reza, S. M. S., Yahya, I., Bais, B., Akhtaruzzaman, M., et al. (2018). Implementation of a novel home energy management system (HEMS) architecture with solar photovoltaic system as supplementary source. *Renewable Energy*, *125*, 108–120. https://doi.org/10.1016/J.RENENE.2018.01.114

Shareef, H., Al-Hassan, E., & Sirjani, R. (2020). Wireless home energy management system with smart rule-based controller. *Applied Sciences (Switzerland)*, *10*(13). https://doi.org/10.3390/app10134533

Syed, I. M., & Raahemifar, K. (2016). Predictive energy management and control system for PV system connected to power electric grid with periodic load shedding. *Solar Energy*, *136*, 278–287. https://doi.org/10.1016/j.solener.2016.07.011

Tostado-Véliz, M., Bayat, M., Ghadimi, A. A., & Jurado, F. (2021). Home energy management in off-grid dwellings: Exploiting flexibility of thermostatically controlled appliances. *Journal of Cleaner Production*, *310*(April). https://doi.org/10.1016/j.jclepro.2021.127507

Tutkun, N. (2014). Minimization of operational cost for an off-grid renewable hybrid system to generate electricity in residential buildings through the SVM and the BCGA methods. *Energy and Buildings*, *76*, 470–475. https://doi.org/10.1016/j.enbuild.2014.03.003

Tutkun, N., & San, E. S. (2013). Optimal power scheduling of an off-grid renewable hybrid system used for heating and lighting in a typical residential house. *2013 13th International Conference on Environment and Electrical Engineering, EEEIC 2013 - Conference Proceedings*, 352–355. https://doi.org/10.1109/EEEIC-2.2013.6737935

Tutkun, N., & Scarcello, L. (2023). Improved Low-Cost Home Energy Management Considering User Preferences with Photovoltaic and Energy-Storage Systems.

Xing, Y., He, W., Pecht, M., & Tsui, K. L. (2014). State of charge estimation of lithium-ion batteries using the open-circuit voltage at various ambient temperatures. *Applied Energy*, *113*, 106–115. https://doi.org/10.1016/j.apenergy.2013.07.008

Zhao, X., Gao, W., Qian, F., & Ge, J. (2021). Electricity cost comparison of dynamic pricing model based on load forecasting in home energy management system. *Energy*, *229*, 120538. https://doi.org/10.1016/j.energy.2021.120538