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Strathmore
UNIVERSITY

SCHOOL OF COMPUTING AND ENGINEERING SCIENCES

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY

Application of Internet of Things (IoT) Sensors to Support Electrical Load Planning in Solar-Powered Resorts in Kenya.

Research submitted in partial fulfilment of the requirements of the Degree of Master of Science in Information Technology at Strathmore University

Faculty of Information Technology

Strathmore University Nairobi, Kenya

April 2024

Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the research proposal contains no material previously published or written by another person except where due reference is made in the research proposal itself.

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12893

Signature……..… Date……8th April 2024..…

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Signature……..… Date……8 April 2024..…

Abstract

Internet of Things (IoT) has evolved has emerged as a powerful new technological paradigm in recent years. It makes it possible to interconnect all types of physical objects and offers real-time collection and processing of sensor data. The rapid development of renewable energy sources, in particular solar energy, has resulted in an increase in availability of clean electrical power that can be efficiently stored and utilized. However, the variability of solar energy based on weather conditions affects its reliability. This makes it difficult for the planning and performing of tasks in resorts, which harness solar energy, such as laundry and food preparation, that require electrical power. This thesis investigates the adoption of Internet of Things (IoT) to optimize the use solar power for meeting electricity demand at solar-powered resorts. This thesis seeks to implement a system that automatically alternates between grid power and solar energy sources, with the aim of optimizing solar energy utilization by performing load planning. This will be achieved by considering the predetermined electrical demand of the resort, employing a predictive model, and using real-time Internet of Things (IoT) sensor data. The prediction model will project solar energy generation which will be compared with real-time IoT sensor readings, for load planning purposes. For the predetermined electrical load of the resort, the system will automatically transition between grid power and solar energy based on whether the two values align or exceed a predefined system threshold. The predictive model will use weather forecast data obtained from publicly accessible sources on the internet, which are usually an approximation, as its input while the IoT sensors will capture real-time measurements relating to weather conditions, solar energy generated and subsequently stored. The overall objective is to optimize the utilization and load planning of solar-generated electrical energy in solar-powered resorts. Ultimately the system will facilitate determination of adequate capacity of expensive solar power storage systems and minimization of the volume of consumed grid electricity. This research adopts an analytical and prototyping methodology. The research will review literature on off-grid solar power installations and their control systems, IoT architectures and Machine Learning techniques which will be adopted in designing the predictive model.

Keywords: solar energy; prediction models; energy management; load planning; Internet of Things (IoT) machine learning; renewable energy forecasting; solar powered resorts

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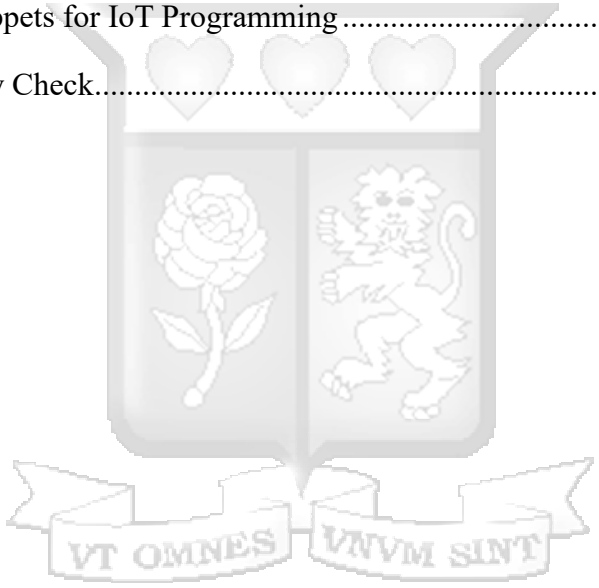

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List of Abbreviations/Acronyms

IoT – Internet of Things

PV – Photovoltaic

DC – Direct Current

AC – Alternating Current

HVAC – Heating, Ventilation, and Air Conditioning

kWh – kilowatt-hour

ML – Machie Learning

DL – Deep Learning

RNN – Recurrent Neural Networks

CNN – Convolutional Neural Networks

API – Application Programming Interface

MQTT - Message Queuing Telemetry Transport

PCB - Printed Circuit Board

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Chapter 1: Introduction

1.1 Background of the study

The world is currently seeing a significant shift in energy systems. The growing awareness of the harmful impacts of fossil fuels on the environment has led to a heightened need for alternate and sustainable energy sources. Solar power has presented itself as a highly promising form of renewable energy, utilizing the vast energy potential of the sun to produce electricity. Over the course of time, there have been significant advances in technology that have resulted in a decrease in the cost of solar panels and an improvement in their efficiency. These developments have therefore enhanced the accessibility and desirability of solar energy across several sectors, including the hospitality industry. The use of solar electricity has generated new prospects as well as challenges within the realm of energy management. The need for developing effective strategies that optimize the efficient utilization and storage of solar energy arises from its inherent unpredictability and intermittency. One significant concern regarding the supply of solar energy is to its inherent volatility and lack of consistency, attributable to its significant reliance on several underlying factors.

With their extensive energy demands, resorts present an attractive opportunity for solar energy use. The need for constant electricity is indisputable. Incorporating solar energy into resort energy systems is thus not only environmentally responsible but also economically attractive. However, the intermittent nature of solar energy, mentioned above, remains a significant obstacle.

The Internet of Things (IoT) is a network of interconnected devices embedded with sensors, software, and connectivity capabilities that enable them to collect and exchange data (Atzori, Iera, and Morabito, 2010). In a nutshell, IoT entails the interconnection of various devices with sensors, allowing for data collection and communication without human interference. By integrating IoT sensors with solar energy systems in solar powered resorts in Kenya, it is possible to perform real-time monitoring, and can provide the ability to manage energy production and load planning in an efficient manner.

IoT technology integration for solar power forecast and optimisation in Kenyan solar-powered resorts is largely uncharted. Weather conditions, cloud cover, seasonal changes and daily cycles make solar energy generation unpredictable, therefore requiring an intelligent system to optimize

its use and production. Previous research has explored the application of IoT in various energy management domains, including smart grids (Siozios et al., 2019), demand response (Bayindir et al., 2016), and energy efficiency (Metallidou et al., 2020). The results of these demonstrations highlighted the vast potential of the Internet of Things (IoT) and its practicality in the renewable energy field. However, the specific application of IoT sensors for optimizing the use and electrical load balancing of solar energy presents a significant research opportunity.

This thesis aims to address the gap highlighted above. By exploring the integration of real-time IoT capabilities, resort energy consumption patterns and needs, and the creation of a predictive model using weather forecast variables, this study intends to develop a solution that enables energy load planning and the seamless switching between solar-generated energy and grid electricity, thereby promoting the efficient use of renewable energy. Such an initiative would not only result in long-term cost savings for resorts, but would also substantially reduce their carbon footprint, nurturing a sustainable future.

1.2 Problem Statement

Although solar energy storage options, such as batteries, are available, they present their own challenges. First, the storage capacity of these solutions is limited, and oversizing storage can incur substantial costs. Secondly, without a predictive strategy, it is difficult to make well-informed decisions regarding when to store energy, when to use it, and when to transition to the electrical grid.

On the other hand, the fast growth of the Internet of Things (IoT) has made it possible to collect, process, and automate data in real time in many areas, such as such as smart cities, health surveillance, and manufacturing and energy management (Zeinab et al., 2017). But resorts haven't done much study on how IoT can be used to predict how much solar power will be available and how to control the electrical load as a result.

Solar-powered resorts can effectively forecast the availability of solar energy by utilizing predictive models and real time monitoring systems, to incorporate a load balancing mechanism that has a bias on utilizing solar generated energy as opposed to grid electricity. The goal is to enhance the ability to providing real-time assistance for electrical load management, therefore enabling a smooth transition between solar and grid power sources. This is expected to target solar-

powered resorts in Kenya, particularly those that are located in regions with the presence of a significant amount of sunshine.

By addressing these challenges, the research seeks to contribute to the field of renewable energy management by developing a system for leveraging IoT sensors to optimize solar energy utilization and perform electrical load planning. The findings of this study have the potential to improve the efficacy, dependability, and sustainability of solar energy systems, allowing for more effective energy distribution and resource allocation.

1.3 Research Aim and Objectives

The primary objective of this study is to contribute to the domain of renewable energy management through the creation of a system that leverages the Internet of Things (IoT) in conjunction with a predictive model. This system is designed to enhance the efficiency of solar energy utilisation and load planning for a predefined electrical load at a resort powered by solar energy. Based on this broad objective is, the specific objectives of the study are:

i. Investigate the effect of weather trends, seasonal changes, and the amount of daily sunlight on solar energy output with its corresponding effect on the range of electrical energy demand at resorts in Kenya.

ii. To design and develop a predictive model for solar energy availability that incorporates inputs related to weather forecasts. These are temperature, humidity and anticipated solar irradiance levels.

iii. To design and implement an automated energy system that seamlessly integrates the predictive model output compared with data from IoT sensors to transition automatically between solar and grid power sources when required.

iv. To evaluate the automated energy system by comparing it to conventional energy load planning techniques employed.

1.4 Research questions

i. What are the primary factors influencing the production of solar energy in resorts, and how do these factors vary at various times of the day?
ii. How do solar-powered resorts in Kenya plan for electrical demand between the grid and solar power?
iii. How do the energy storage capacities and power ratings of solar panels affect the precision and dependability of solar energy forecasts?
iv. How can real-time data from Internet of Things (IoT) devices and predictive models be combined to create an effective automated mechanism for automatic switching between solar and grid power?

1.5 Justification of the study

Solar power has emerged as one of the most predominant renewable energy sources in the current era, which is marked by a significant transition towards sustainability and energy efficiency. Due to their expansive landscapes and high energy consumption patterns, resorts present a unique opportunity to use solar energy, reduce carbon footprints, and improve economic efficacy. The below factors support the decision to investigate the use of IoT sensors for capacity planning in such establishments:

First and foremost is the adoption of renewable energy solutions. There is a growing global awareness of environmental issues, and as a result, numerous industries are adopting green technology. Exploring how IoT can optimize resorts' use of solar energy could substantially advance global sustainability objectives.

Second, economic efficiency is of significant importance. Utilizing efficient load planning strategies has the potential to result in significant cost savings. By implementing automation with IoT sensors, resorts can optimize their energy consumption, reduce resource waste, and lower energy costs.

Thirdly, technological advancement is important as well. The advent of IoT presents unmatched prospects for the gathering of data and the implementation of automation across many industries. Solar energy systems and IoT represent the convergence of two transformative technological

domains. This study's examination of their integration may reveal innovative approaches not only for resorts, but also for a wide variety of industries and applications.

Last but not least is Operational Excellence. Effective load planning that is informed and automated by IoT can result in more efficient resort operations. Avoiding energy shortages or overloads can improve the guest experience by ensuring that all amenities function properly.

1.6 Scope of the study

The focus of this study, being comprehensive and carefully defined to guarantee a focused approach, revolves around small to medium sized resorts located in Kenya that have an abundance of sunshine, that have adopted solar energy, either as their primary source or as a supplemental source. The study will focus on these resorts, to provide a consistent context for data analysis. This is done to acknowledge the impact of geographical elements, such as weather patterns and sun irradiance, on solar energy production. The findings will thus be most directly relevant to enterprises in the hospitality industry that have comparable energy demands and operating patterns, even though they may be adaptable in other contexts.

The research will make use of historical data to ensure relevance and currency. Predictive modelling will concentrate on forecasting the availability of solar energy for specific time intervals. While IoT encompasses a vast multitude of devices and technologies, this study will focus on those most appropriate to energy monitoring, administration, and automation within the context of solar power. The focus of investigation will be on IoT sensors specifically designed for monitoring energy consumption, solar power generation, and energy storage dynamics. The integration of current IoT technologies with solar power systems will be the study's main focus. It will evaluate the effectiveness of already existing technologies rather than getting into the design or development of new IoT devices. This deliberate choice excludes other areas of IoT, such as guest experience optimization or security measures.

This study will examine both predictive approaches, which estimate energy requirements, and responsive tactics that enable real-time adjustments, within the field of energy load planning.

Chapter 2: Literature Review

2.1 Introduction

This chapter examines the characteristics of solar power as an energy source, from it its acquisition and storage for use as a renewable energy source. This section will also examine the technologies implemented in relation to solar energy usage. In addition, this section will examine IoT and its contribution to technology, as well as the application of solar energy predictive models. An investigation of related works will also be done here. To conclude will be a conceptual framework of the proposed system.

2.2 Solar Power: Essence, Generation, and Storage

Solar power generation is the process of capturing the sun's radiant energy and converting it into usable electricity; it provides a sustainable solution to growing environmental concerns. The underlying science and technology involve a harmonized integration of various hardware components and methodologies that facilitate its capture, conversion, and storage (Lewis, 2007). Understanding the mechanisms of solar power generation, storage, and its potential is essential for resorts wishing to harness this limitless energy source. This section examines the essential components for solar power generation, including the various varieties of solar panels, their capacities, and the methods for quantifying the generated energy.

2.2.1 Fundamentals of Solar Power Generation

Several integral components are necessary for the conversion of sunlight to electrical energy: Solar Panels are the primary means by which solar energy is generated is using solar panels, which consist primarily of Photovoltaic (PV) cells. These cells are composed of semiconductor materials which possess the ability to absorb photons emitted by sunshine. This absorption process initiates the movement of electrons, resulting in the generation of direct current (DC) power. Solar panels have various ratings, which usually correspond with their efficiency and capacity. As an example, monocrystalline panels, distinguished by their singular crystal structure, frequently exhibit superior efficiency (about 15-20%) because to their high purity silicon composition (Levi et al., 2017). On the other hand, polycrystalline panels are made up of multiple silicon crystals, resulting in a somewhat lower efficiency range of around 13-16% (Szlufcik et al., 1997). In addition to the above options, there are thin-film solar panels and other specialized types that offer diverse

efficiency ratings. When evaluating the potential of solar power, it is best practice to quantify the panels in terms of their wattage, which signifies the amount of energy they can generate under optimal sunlight circumstances.

It is important to consider that following the energy collection phase, the direct current (DC) power generated by solar panels is incompatible with the majority of equipment and appliances that are designed to operate on alternating current (AC). A device referred to as an Inverter is responsible for the function of transforming direct current (DC) power into alternating current (AC). The efficiency of an inverter can have a substantial effect on the net power output of a system.

Typically, devices referred to as solar meters are used to measure the kWh (kilowatt-hours) of electricity produced by solar panels. Solar meters aid in monitoring daily, monthly, or annual energy production, thereby facilitating comprehension of system performance and troubleshooting. A solar charge controller is a device responsible for regulating voltage and current when charging a battery with photovoltaic panels. Without this device, overcharging would damage your batteries. Charge controllers are necessary in a solar system setup.

Given the intermittent nature of sunlight, it becomes imperative to store excess energy during peak production hours. Solar batteries perform this function. They store excess energy produced during the day, making it accessible at night, on cloudy days, or when consumption exceeds production. Modern solar batteries are designed to store DC energy, enabling its consumers achieve greater energy independence by reducing their reliance on conventional grid electricity.

In essence, solar power represents an optimistic convergence of nature's limitless resources and human innovation. Solar power opens the way for a brighter, greener future by expertly combining components such as solar panels, inverters, and batteries, as well as continually monitoring and assessing their performance. Figure 2.1 below shows the components that make up a photovoltaic off grid system discussed above.

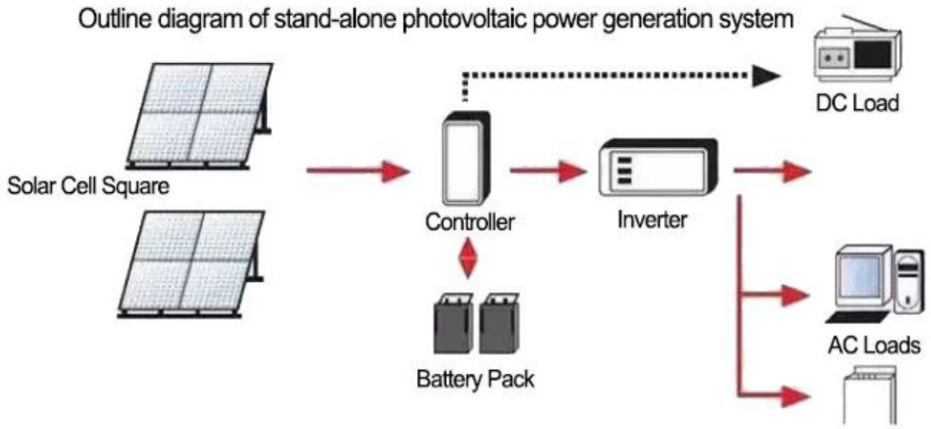

Figure 2.1: Photovoltaic off grid system components

Source https://www.inverter.com/

2.3 Solar control systems

Dincer (2000) explains that solar power systems are becoming more and more common as the world shifts to renewable energy sources. They will soon make up a significant portion of the energy infrastructure of resorts. Solar control methods have been created, utilizing innovations like IoT sensors, to maximize the performance of these systems. This subsection provides a literature review on various solar control systems, their technological underlying principles, and their role in optimizing solar energy use in resorts.

2.3.1 Technological Landscape

Solar control systems are leading the way in optimizing and simplifying energy output in commercial solar projects. These complex systems enable real-time monitoring and extensive recording of solar setup performance metrics (Vijay et al., 2013). Many business enterprises, for example, use sophisticated metering technology to precisely track kilowatt-hours (kWh) generated and consumed, assuring energy efficiency, and perhaps permitting reimbursements or credits from power system contributions. Some technologies around solar control systems are listed below:

Maximum Power Point Trackers (MPPTs): One of the key technologies utilized in solar control systems is the Maximum Power Point Tracker (MPPT). The primary function of this system is to ensure the best possible performance of solar panels by continuously adapting to changing environmental circumstances, therefore maintaining the panels at their maximum power point.

According to researchers Esram and Chapman (2007), it has been observed that maximum power point trackers (MPPTs) have the potential to greatly enhance the efficiency of solar power systems.

Battery Management Systems (BMS): The battery management system (BMS) is an essential component for resorts that make use of battery storage. According to researchers Huang, Wen, and Chen (2014), battery management systems (BMS) make certain that batteries function within their safe limits, hence maximizing their capacity and prolonging their lifespan.

Solar Inverters with Communication Capabilities: Solar inverters with communication capabilities have been increasingly prevalent in recent years. These advanced inverters are designed to enable remote monitoring and administration, hence enhancing the efficiency and effectiveness of solar power systems. Inverters in grid-tied solar systems play a very significant role, as they enable dynamic load changes and peak shaving (Xue et al., 2013).

2.3.2 Internet of Things (IoT) Integration

With the advent of the Internet of Things (IoT), solar system administration and control have undergone a revolutionary shift. Internet-connected IoT devices provide an unprecedented level of system oversight granularity. Multiple factors, including weather conditions, solar irradiation levels, battery charge levels, inverter output, and system health, can be monitored on a real-time basis. In addition, by leveraging data analytics, these devices can predict maintenance requirements, alter panel angles for optimal solar exposure, and even manage energy distribution based on real-time demand and anticipated energy requirements. Monitoring systems based on IoT must be able to measure and capture data, transmit data to servers, and display and analyze the transmitted data. To select the optimal system components for the current PV power system in terms of communication, speed, and precision, it is necessary to assess the IoT technologies and hardware modules recently employed in monitoring PV power systems (Boubakr et al., 2022). For the purpose of this thesis see below relevant items incorporating IOT to capture measurements that are:

i. Solar Irradiance Levels - Solar Radiation Sensors: Solar radiation sensors are a type of device utilised for the purpose of quantifying solar irradiance, which refers to the amount of electricity received per unit area from the Sun. These sensors possess the capability to view and record data in real time. These couple coupled with IoT integration allow for relaying this data.

ii. Temperature & Humidity - Temperature and humidity sensors: In the context of monitoring weather conditions for solar power generation, these sensors remotely detect and communicate data on temperature and humidity levels on a real time basis. These metrics may be essential for comprehending and maximizing the production of solar energy.

iii. Current/voltage sensor: These measure the current or voltage level and tell a control system how much Direct Current (DC) is being relayed from the solar panels.

iv. Real-time Battery Energy Storage Levels: Sensors for battery energy storage are essential components of solar energy storage systems, providing real - time information on the battery's condition of charge. This information used in the right way can enhance how to plan for solar energy consumption.

2.3.3 Solar Control Systems in relation to variability of Solar Energy Production

Solar energy production is governed by a variety of controllable and uncontrollable variables. This includes the type and efficacy of solar panels, geographic location, panel orientation, and daily duration of sunlight. To evaluate energy production, it is essential to understand the relationship between input and output energy. For instance, a standard commercial solar panel with an efficiency rating of 18% would generate approximately 180 watts per square meter when exposed to full sunlight (Levi et al., 2017). Factors like as cloud cover, deterioration of solar panels over time, and seasonal variations might have an influence on these measurements, highlighting the significance of implementing dynamic monitoring systems.

In conclusion of this subsection, it is noteworthy to highlight that Solar control systems have become essential instruments for maximizing the efficiency of solar arrays in resort settings. Through the utilization of technological breakthroughs such as Maximum Power Point Tracking (MPPT), Battery Management Systems (BMS), and Internet of Things (IoT), these systems successfully synchronize solar power generation with consumption patterns, hence facilitating the adoption of sustainable and efficient energy practices. Furthermore, the incorporation of IoT into solar control systems is reshaping how commercial entities harness, monitor, plan for and optimize solar energy usage. These systems ensure that the transition to renewable energy sources is not

only sustainable, but also efficient and maximally beneficial by providing a comprehensive view of the entire solar installation and providing actionable insights.

2.4 Use of Predictive Models for Solar Power Generation

Predictive modelling is important in many fields, including the renewable energy sector. Predictive modelling uses data analytics and statistical methods to predict possible results based on previous data. In the field of solar energy, prediction models are very helpful because they can predict how much energy will be made based on various factors. Such predictions can be very important in situations like planning the amount of electricity used in solar-powered resorts.

Predictive modelling may be seen as a function that accepts past data as an input and generates predictions for upcoming occurrences using a variety of techniques. The quality and quantity of the data supplied into the models, as well as the suitability of the selected algorithms, all affect how accurate and reliable such forecasts are (Brownlee, 2016). In essence, it makes use of the links and patterns found in previous data to offer knowledgeable predictions about what could happen in the future.

2.4.1 Projected Meteorological Factors in Predictive Models

Predicting solar energy production relies heavily on the following weather factors:

i. Temperature: the degree or intensity of heat present in the atmosphere. This is considered a vital predictor in solar energy generation.

ii. Humidity: Higher levels of humidity can reduce the amount of sun energy, which affects the solar energy generated.

iii. Cloud Coverage: The amount of cloud cover can have significant impact on how much sunlight reaches the solar cells.

iv. Anticipated Sun Irradiance Levels: The anticipated amount of solar radiation reaching the Earth's surface plays a pivotal role in forecasting the generation of solar energy.

2.4.2 Harnessing Data from Datasets for Prediction Model

So as to forecast solar energy generation, we must aggregate and analyse data from datasets for the prediction model. Cleaning, preprocessing, and applying machine learning algorithms are the steps involved in this process to identify patterns and trends. Through the consumption of this data, the predictive model is able to forecast solar energy availability in the future, which can lead to improved resource allocation and energy efficiency.

2.5 Solar-Powered Resorts in Kenya

In pursuit of a sustainable energy future, more resorts in Kenya are turning to solar power and other renewable energy sources. Due to Kenya's proximity to the equator, solar energy is abundant throughout the year. Its radiation level is between 4 and 6 kWh/m2/day, and its total potential is 23,046 TWh per year, making it suitable for solar PV and concentrated solar power systems (Huseynli, 2022). As these resorts make this transition, it becomes essential that they understand and plan for their unique electrical loads. This sub section of the literature review discusses the electrical load characteristics in these resorts and the incorporation of renewable energy, with a focus on the observable and quantifiable components that IoT sensors could potentially optimize.

2.5.1 Characteristics of Electrical Load in Solar-Powered Resorts

Appliance-Based Load Profiles: Laundry machines, food preparation appliances such as ovens, refrigerators, and dishwashers, water heating systems, and heating, ventilation and air conditioning (HVAC) systems are commonly found in resorts. Many of these appliances have a relatively predictable electrical load. Once the significant appliances and devices in resorts have been identified, it is possible to anticipate and plan for their electrical consumption patterns. Similarly, manufacturers frequently catalogue the energy consumption of standard kitchen equipment, allowing for accurate load predictions (Deng & Burnett, 2002).

Daily and Seasonal Variation (Dynamic in nature): Beyond appliances, resorts experience daily and seasonal variations in electrical demand. Typically, peak periods coincide with guest activities, such as morning routines and evening entertainment (Bromberek, 2009). The seasonal aspect is

frequently affected by peak tourism seasons and off-seasons, which can have a substantial impact on total energy consumption (Baum & Lundtorp, 2001).

Grid Electricity Integration: Resorts that are integrated into the electrical grid possess the ability to determine their preferred approach for incorporating specific electrical load items that exclusively rely on grid electricity, while simultaneously having a strategy that uses both grid electricity and solar energy for other electrical loads, based on the availability of each energy source.

2.5.2 Factors Affecting Electrical Load

Guest Profile and Behaviour: Depending on the type of visitors and their consumption habits, energy demands can vary. Different groups, such as families, business travellers, and couples, may consume energy differently, thereby affecting the burden (Becken et al., 2003).

Climatic Conditions: Climatic variations can lead to significant shifts in energy demand. For instance, in tropical regions, air conditioning usage can surge during hotter months, whereas heating becomes a priority in colder climates (Becken & Hay, 2007).

2.5.3 Renewable Energy Integration and Load Planning

Understanding load profiles, particularly the predictable components, becomes essential as resorts integrate solar power. (Scott, Gossling, and Hall, 2012) The intermittent nature of solar energy necessitates effective load management to guarantee efficient utilization.

Role of Internet Sensors: There is the potential for real-time monitoring and more efficient management of predictable electrical load with the introduction of internet sensors. By providing continuous data on energy consumption, these sensors can assist in aligning solar generation with the actual and anticipated demands of resort appliances and systems (Bedi et al., 2018).

2.6 Related works

The adoption of solar power has been driven by the increasing emphasis on sustainability and the incorporation of modern technology into the energy sector. Utilizing solar energy, the Internet of Things (IoT), and predictive modelling offers transformative sustainable energy solutions. With their fluctuating energy demands, resorts stand to gain the most from this synergy. Incorporating predictive models enhances the capability to automate the switch between grid and solar power, thereby assuring the most efficient energy utilization. This section examines previous research on the confluence of internet sensors, solar energy, and predictive modelling, with a focus on resort settings.

2.6.1 BBOXX- a Solar Home Systems solution using Internet of Things

The BBOX Solar Home System (SHS), commercial solution, is a plug-and-play solution that generates electrical power for a residential installation and provides affordable, dependable, and environmentally friendly energy solutions. This approach is primarily geared at individual residences and focuses on the management of solar energy within the context of a household in which there is either a limited supply of electrical energy from the grid or none at all. The main idea behind this solution was clear: traditional solar systems, while good, didn't have the knowledge and flexibility to meet different energy needs. Figure 2.2 below captures the depiction of the BBOX commercial solution components.



Figure 2.2: BBOX Components: A SMART Solar Home System

Source https://www.bboxx.com/

The BBOX Solar Home System (SHS), implementation is done as a package that combines solar panels and Battery boxes, in which the solar energy will be stored. Using photovoltaic technology, solar panels harvest solar energy, for storage in in batteries. The energy stored in these battery

boxes is then used to give its users the ability to power a variety of small equipment, ranging from lights and mobile phones to televisions, refrigerators, and laptops.

BBOX has a technological monitoring system that continuously assesses battery life, energy consumption patterns, and system performance, identifying problems as soon as they arise. With the use of this data, the provider can execute preventative maintenance to extend system lifespan and performance while lowering operational costs and user involvement in the event of a problem. (Tejwani et al., 2014). The implementation of Internet of Things (IoT) technology has been included as part of these boxes primarily for the sake of facilitating monitoring and controlling processes.

The fact that battery boxes can only store and supply solar energy to a single residence is one of the most significant limitations imposed on their application. There is no way to accurately predict or forecast the quantity of solar energy that can be effectively controlled and stored. This research intends to take this a step further to fill the identified gap by proposing an application that will use a predictive model to not only forecast solar energy generation levels, but also provide the information necessary for decision-making regarding the amount of electrical load that can be placed on the predicted solar energy. This will be accomplished by employing a predictive model to not only forecast solar energy generation but also solar energy consumption.

The BBOX solution functions as a guide for this research by drawing parallels. Solar energy forecasting, the Internet of Things, and predictive modelling and power source selection automation are central to this thesis. This research will improve and better integrate various components related to IoT and come up with a predictive model by building on some of the implementations done by BBOX as a reference.

2.6.2 A Smart solar PV monitoring system using IOT.

This study presents a cost-effective Smart Solar PV Monitoring System that utilizes IoT technology to maximize the efficacy of solar panels by continuously detecting performance degradation (Kavitha & Malathi, 2019). The proposed system captures and analyses solar energy parameters in real-time, these are; current, voltage, irradiance, and temperature, to ensure stable power generation and optimum performance. The system is designed to be user-friendly and accessible via a cloud platform, which provides ample storage space and quick data access.

The study utilizes a combination of several sensors, such as current, voltage, and temperature sensors, to get valuable information on the operating condition of solar panels. The data collected by the sensors was inputted into a microcontroller that was connected to an Internet of Things (IoT) module. The implementation of this module enabled the seamless transfer of gathered data to a cloud-based platform, hence offering convenient remote access and monitoring capabilities. This is achieved by having a three-layer IoT-based real-time solar energy monitoring system. The lowest layer contains sensing and actuating devices. The middle layer encompasses network layer for connectivity and the top layer (application layer) used to deliver data to user interface. The related work mentions the use of a high precision pyranometer to measure solar radiance and an LM35 sensing device to measure the present temperature in the solar panel, but does not specify the accuracy of the system employed. These two parameters are said to have a significant impact on the solar panel's efficacy. The paper also describes the use of a smart controller based on the HEM algorithm to maximise the use of solar PV for residential energy management. Overall, the proposed system is intended to capture and analyse solar energy parameters in real time to guarantee stable power generation and optimal performance.

The strengths noted from this study are listed below:

- Real Time monitoring: This system provides real-time data acquisition, which provides immediate insight into the efficacy of solar PV panels. This allows for timely interventions should anomalies or inefficiencies be identified (Kavitha & Malathi, 2019).
- Remote Monitoring: The incorporation of IoT enables users to monitor their systems from any location, thereby reducing the need for on-site inspections and facilitating remote energy management that is both effective and efficient.
- Maintenance Planning: The system's ability to monitor and report on multiple parameters may aid in foreseeing when maintenance is required, thereby reducing downtimes and extending the solar installation's lifespan.

Some limitations noted from this study are listed below. This thesis will look to cover these gaps identified. This research will try to solve the issues that have been identified as limits, which are listed below.

- Limited Inputs: There are a few characteristics that are employed in the process of measuring the creation of solar energy. These qualities include temperature, the quantity of solar irradiation, and the generated voltage. The end goal of this research is to broaden the scope of the parameters.
- Lack of any prediction models: This study did not specify a prediction model. The suggested system collects and analyses solar energy characteristics in real time for consistent power generation and optimal performance. Continuous monitoring detects performance deterioration to optimize PV panel efficiency using a cost-effective smart design. The cloud-based solution is user-friendly and provides enormous storage capacity and rapid data access. The study explains how a HEM algorithm-based smart controller maximizes solar PV for household power management. The study does not specify a prediction model. My proposed research aims to utilize a predictive model that not only offers predictions based on data gathered from Internet of Things (IoT) devices but also provides crucial input for facilitating automated switching between grid electricity and anticipated solar energy generation.

Notable similarities of this research to this thesis are listed below:

- Integration of IoT with Solar Systems: Both my proposed research and Kavitha and Malathi's related work highlight the critical importance of integrating IoT devices with solar energy systems. This integration is essential for capturing real-time data from various solar system components, allowing for continuous monitoring and potentially enhancing the overall efficiency and dependability of the solar power equipment.
- Predictive and Real-time Analytics: The core of Kavitha and Malathi's proposition is the ability to provide users with insights into the efficacy of their system. This aligns with the theme of the research I propose, which concentrates on the use of predictive models to facilitate the automatic transition between solar power and grid systems. Utilizing real-time data to anticipate future needs and challenges, thereby making systems more resilient and adaptable, is emphasized.

2.6.3 Forecasting Renewable Energy Generation with Machine Learning and Deep Learning: Current Advances and Future Prospects.

The study investigates the potential surrounding machine learning (ML) and deep learning (DL) techniques in forecasting renewable energy generation in their extensive study (Benti et al., 2023). They provide insight into the effectiveness of predictive models in the domain of renewable energy by compiling extant methods and their respective performances.

This related work performs research around various Machine Learning and Deep Learning models, evaluating them on metrics such as precision, dependability, and computational efficiency. While ML models such as regression trees and support vector machines are explored, research is also ongoing on DL models such as neural networks and recurrent neural networks (RNN), due to their potential to manage enormous datasets and complicated temporal interactions.

Some key results and findings from this work are listed below:

1. Deep Learning Research:

- Deep learning models can handle big and complex datasets, pick up on links that don't follow a straight line, and learn from raw data without having to add features.

- Recurrent neural networks (RNNs) and convolutional neural networks (CNNs) are two famous deep learning models that are currently under investigation as regards their potential to predict the future of green energy. In general, RNNs are more accurate than CNNs.

2. Model Complexity vs. Computational Efficiency:

- There is a strong correlation between the level of accuracy of a model and its level of complexity; however, this complexity also makes the model more difficult to execute.

-Traditional machine learning models like linear regression and decision trees are easy to run on a computer, and on average offer an accuracy level of 90 to 95%.

- Deep learning models like RNNs and CNNs are known to use a lot of computing power and take hours or days to train.

- Random forest is a mixed model that blends the accuracy of deep learning with the speed of traditional machine learning. It has accuracy levels from 90% to 95% and training times are much shorter, ranging from minutes to hours.

Some key learnings from this research that will be included in the thesis are highlighted below:

Operationalizing Deep Learning: Ongoing research shows that some DL models, have demonstrated some level of promise in renewable energy forecasting, their implementation in forecasting solar generation for resorts can be crucial. On the other hand, additional research and analysis, particularly concerning the execution, is still required, noting that these models do require a lot of processing power. Also, it is important to note that that these models would have to be adapted to resort-specific datasets that include variables such as daily solar insolation and seasonal variations.

Feedback Loop Integration: Post-prediction, a feedback loop can be integrated. This means that real-time data, facilitated by internet sensors, is continually fed back into the model, refining and enhancing its predictive capabilities over time.

VT OMNES VNVM SINT

2.7 Conceptual Framework

The conceptual structure of the proposed system is depicted in Figure 2.3 below. The system illustrates how the specifics of electrical demand for a solar-powered resort, data from externally accessible sources such as the internet, and IoT sensor measurements interact. The outcome of the interaction will be electrical load planning leading to the efficient utilization of solar energy.

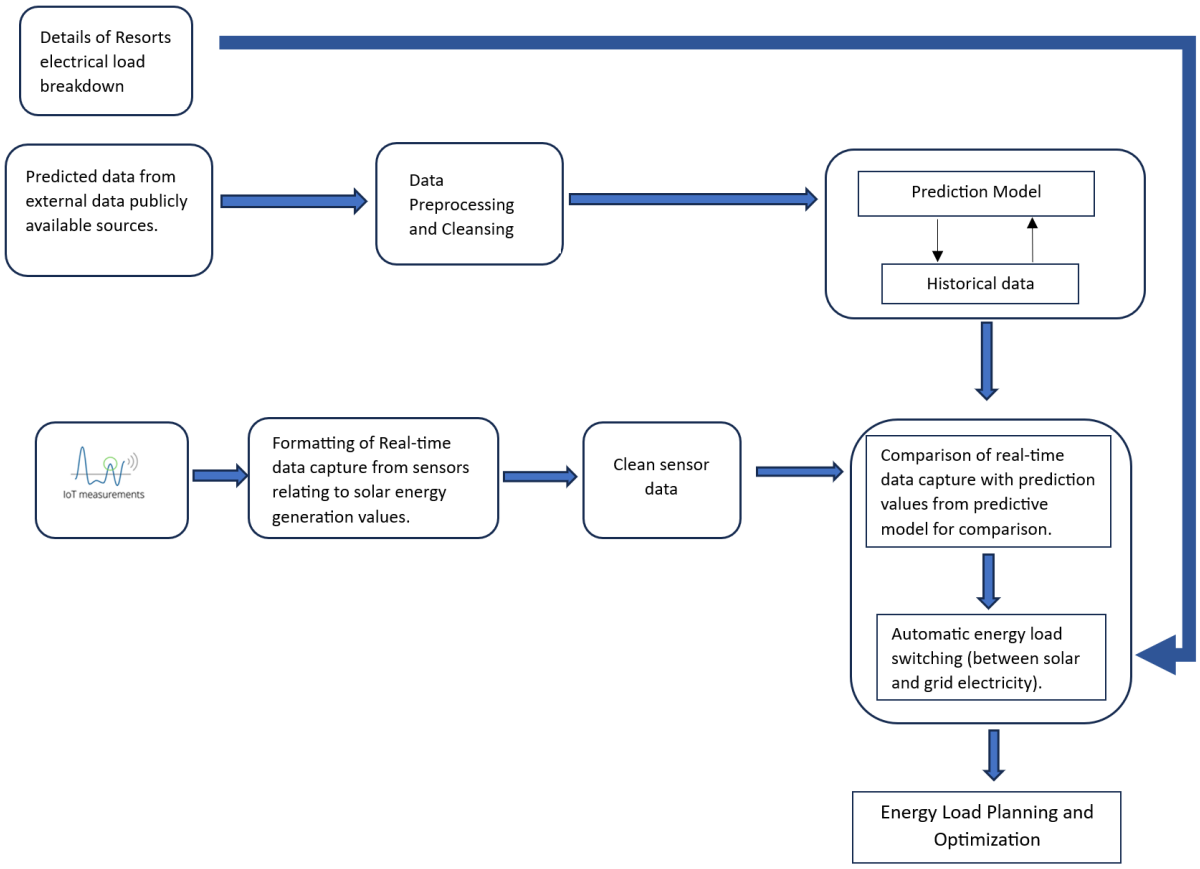

Figure 2.3: Conceptual Framework

2.8 Conclusion

Despite the fact that resorts present a complex and variable electrical demand profile, a significant portion is predictable due to standardized appliances and systems. The incorporation of internet-based sensors offers a promising method for optimizing the alignment of this predictable burden with solar energy production, thereby ensuring efficient energy utilization through load planning.

Chapter 3: Methodology

3.1 Introduction

This chapter focusses on the methodology which is the foundation of the study and offers a clear framework for the research procedure. It includes all the methods, equipment, and processes used in data collection and analysis. This chapter explains the structured processes used for data acquisition, model development, prototype creation, and evaluation to ensure the credibility and precision of the research's objectives.

3.2 Research Design

This study's research design is based on the combination of the Internet of Things (IoT) and solar energy load planning, with a focus on solar-powered resorts in Kenya. Given the inherent variability of solar energy due to changing weather conditions, there is an urgent need to improve the dependability of solar energy for energy-intensive duties. To resolve this issue, the research seeks to develop a system that seamlessly alternates between grid power and solar energy, thereby maximizing solar energy load usage.

The basis of this design consists of three components: The electrical load that is used at a solar powered resort that is expected to be planned, real-time IoT sensor data and a predictive model. The predictive model, informed by publicly available weather forecast data, such as AccuWeather APIs as an example, will estimate solar energy production potential. These forecasted data, while useful, are frequently approximations. To counteract this limitation and ensure precision, IoT sensors in real time are incorporated. These sensors will continuously monitor and record relevant information, being current weather conditions and the eventual amount of solar energy generated. By comparing the projections of the predictive model with the real-time data from the IoT sensors, the system is able to make informed decisions that result in electrical load planning transitions. For example, the system will favour solar energy if the resort's electricity needs hit a certain level and the real-time sensor data matches or beats the predictions of the forecast model. On the other hand, if there is a difference or not enough solar energy, the system will switch back to grid power. This dynamic method makes sure that the resort uses as much solar energy as possible while using as little power from the grid as possible.

3.3 Research Approach

The initial step of the approach begins by examining the relationship between weather patterns, including daily sunlight exposure, seasonal variations, and their resulting effect on solar energy output. This research is essential for comprehending the inherent variability of solar energy, particularly in the context of Kenyan resorts.

The next step of the research's approach is to assess the needs of electrical energy demand in these resorts. By identifying the energy consumption patterns, the research will be able to modify the predictive model and IoT system to better meet these specific needs as this will facilitate load panning.

Design and development of a predictive model will be implemented using relevant machine learning techniques which have shown to be better suited for the data related to weather predictions such as temperature, humidity, and anticipated solar irradiance levels, seeks to forecast potential solar energy outputs. Acknowledging the limitations of forecasted data, the study introduces the use of IoT sensors that collect data in real time. These sensors selected based on their ability to measure environmental conditions such as solar irradiance, temperature, and humidity, as well as data related to amount of solar power generated to provide a real-time contrast to the predictive model's solar power projections.

The research seeks to develop an automated energy system based on this foundation. By integrating the outputs of the predictive model with real-time IoT sensor data, this system can dynamically switch between solar and electrical power sources The focus here is on ensuring a seamless transition with minimal response time, thereby enhancing electrical load planning and maximizing solar energy usage.

The newly developed automated energy system is compared to conventional energy load planning strategies. The result of this comparison not only emphasizes the effectiveness of the technology but also illuminates its potential benefits in the context of optimizing load planning in solar energy for resorts.

3.4 Population and Sample Size

The study's foundational population comprises three independent solar-powered resorts located in Kenya, each characterized by its own distinct geographical and climatic environment. Interviews will be conducted with two senior operations managers or personnel from each resort who possess comparable expertise in the management of energy consumption at the resort. I pledge to uphold ethical standards by ensuring that all participants' dignity and rights are respected. This will be achieved through the provision of transparent and comprehensible information and the acquisition of consent in a manner that is equitable and attuned to cultural nuances. Every effort will be put forth to ensure that the research inquiries and the approach to involvement are considerate of the rights of any vulnerable individuals and reverent of the cultural values of the participants.

3.5 Data Collection and Analysis

3.5.1 Data Collection

The data collection strategy will employ a comprehensive approach, integrating structured interviews with resort management and the acquisition of personal insights via direct observation and surveillance of resort operations. In addition to this methodology, secondary data analysis derived from academic research, industry reports, and other relevant publications will be conducted. All participants will receive an unequivocal assurance that their privacy and confidentiality will be maintained throughout the entirety of the research endeavour. See additional data sources that will be specific to this research.

Meteorological data: Weather Data: This will include data on daily sunshine exposure, seasonal fluctuations, temperature, humidity, and cloud covering to determine how weather patterns affect solar energy output. It will mostly be obtained from publicly available sources such as Accuweather.com. This platform is renowned for its extensive and reliable weather forecasting capabilities.

Resort Electrical Energy Demand: By means of conducting surveys and interviews with technical staff and resort management, the objective is to acquire extensive knowledge regarding the energy consumption trends exhibited by resorts in Kenya. In instances where they are accessible, historical records of energy consumption will be examined to acquire a deeper understanding of the dynamics of energy demand.

Real-time sensor readings: I shall personally finance, to the best of my ability, the deployment of Internet of Things (IoT) sensors. This investment will enable the accumulation of real-time data pertaining to various parameters, including, solar irradiance, ambient temperature, humidity, electrical current and voltage output.

3.5.2 Data Analysis

3.5.2.1 Prediction Model

The predictive model is expected to project solar energy outputs using data analysed from forecast weather sourced from Accuweather forecast API. This data will consist of forecast meteorological data. IoT sensor readings will be used to develop and train the model over time to improve accuracy.

3.5.2.2 Prediction Model Data Set

The primary datasets utilized for the model training be obtained from Kaggle.com, a reputable platform that provides a wide range of real-world datasets across several industries. The extensive dataset repository provided by Kaggle, together with its active community, has continually facilitated progress in several academic domains, including the development of prediction models for renewable energy.

The details of the dataset are outlined below.

Solar Power Dataset: Weather conditions and solar power generated for every 2-minute interval. Source: https://www.kaggle.com/datasets/s1nister/solar-power-generation-dataset

Attributes:

Air_Temp: Temperature measured in degrees Celsius (C)

Relative_Humidity: Relative humidity is measured as a percentage (%RH).

Wind_Speed: Speed of wind measured in metres per second (m/s)

Wind_Direction:Wind Direction measured in degrees.

Solar_Radiation: Solar Radiation measured in watt per square meter (W/m^2)

Array_Voltage: Voltage generated measured in Volts

Array_Current: Current generated measured in Amperes

Power_Generated: The power generated (Watt) is based on the voltage and current readings (Array_Voltage * Array_Current).

Nature of Dataset: The dataset comprises various environmental factors and readings, with the goal of predicting Power_Generated- a continuous variable. The dataset includes features like Air_Temp, Relative_Humidity, Wind_Speed, Wind_Direction, and Solar_Radiation, which suggest complex, potentially non-linear relationships with the target variable.

3.5.2.3 Prediction Model Training

The aforementioned dataset will be thoroughly analysed to identify the best opyion for dividing the data into training and testing subsets in order to support in the model's training. Using this analytical method is critical to developing a model with the maximum level of accuracy. So as to improve the model's performance and reliability in real-world scenarios, this process aims to ensure that the model is efficiently trained on a representative sample of the dataset while setting aside a different amount of data for testing its prediction capabilities.

3.6. User Responses

The combination of user feedback obtained from interviews conducted with three unique groups - industry experts and academics, resort managers, and technical specialists - provides a comprehensive viewpoint on the incorporation of IoT technology in in solar-powered resort energy management systems.

Industry Experts and Academics underscored the significant impact of Internet of Things (IoT) applications on energy management, with a specific focus on the solar energy industry. Their interest in merging IoT with renewable sources was driven by efficiency gains and the need for sustainable energy. They stressed the need of IoT sensors in real-time monitoring and predictive analytics for electrical load planning. The optimism was tempered by issues like high starting costs, maintenance, and the need for customised solutions for Kenya's environmental and socio-economic conditions. Future trends predicted more autonomous systems, with AI and machine learning improving IoT's renewable energy management applications.

Resort managers discussed their energy management plans, showing a strong desire to make use of solar power for its environmental and cost-saving benefits. The benefits of operational

efficiency and sustainability were underlined as some explored IoT technologies to enhance operations. Management wanted IoT technologies to improve electrical load planning, but technical skills and upfront expenses were obstacles. The company prioritised sustainability, and solar power helped with long-term planning and operations.

Technical Specialists discussed site-specific concerns and environmental issues affecting sensor selection and placement in solar-powered systems. Planning and integrating IoT for data-driven energy management decision-making was crucial to successful installations. It was stressed that data handling techniques must be secure to protect sensitive data. Many discussed IoT integration's economic implications and ROI, citing long-term savings and efficiency improvements compared to initial investment and continuing maintenance.

3.7 Research Quality

This research maintains its quality by conforming to the principles of validity, reliability, generalizability, and openness throughout its approach. Tools and procedures are selected with careful consideration to guarantee accurate measurements, and the development of the prediction model as well as the choice of IoT sensors are what contribute to the increased internal validity. The use of the Agile approach and testing steps helps to maintain the consistency of the study, which ultimately leads to a higher degree of accurate results. Although the study focuses on resorts in Kenya that are powered by solar energy, the methodology and ideas that it presents have a wider applicability, which extends the study's usefulness beyond the local setting. Every step of the research process is carefully documented, which promotes transparency and makes it possible for others in the field of renewable energy management to replicate the study and conduct more research on the subject.

3.8 System Development Methodology

The implementation of an automated energy system involves the adoption of an Agile Systems Development Methodology, which places significant emphasis on flexibility and iterative development. to supplement this methodology, will be the inclusion of is both Analytical and Prototyping methodologies. The Analytical approach offers a systematic framework for deconstructing and comprehending the requirements of a system, using observations from meteorological patterns, solar energy generation, and the unique energy needs of resorts in Kenya. The Prototyping approach is combined with a well-defined analytical basis, enabling the iterative

processes of design, testing, and refining. The iterative process is guided by feedback loops, which contribute to the ongoing enhancement of the system. The Agile methodology, which incorporates both thorough analysis and practical prototyping, guarantees the creation of a system that has the ability to adjust and respond to changing real-world circumstances and obstacles.

3.9 Design & Implementation

Design and Implementation lays the foundation for the automated energy system's development, ensuring research results are translated into a practical solution.

System design will cover the below items:

System Architecture: This design shows how the predictive model, IoT sensors, and energy transition mechanism interact to ensure data and control flow.

IoT Integration: The design puts emphasis on the realistic placement and inclusion of (IoT) sensors to make sure they can measure environmental and energy metrics in real-time.

Predictive Model Design: The design of the model will be suited to incorporate weather prediction data, allowing for the projection of possible solar energy outputs, and providing flexibility in accommodating various inputs. The prediction model will undergo training using a dataset consisting of two years' worth of historical data. Validation procedures will be established to assess the precision of the model and guarantee that its predictions remain under a 5% margin of error. To achieve model optimization, the model will be subjected to iterative improvements aimed at enhancing precision and reducing errors.

System implementation will make use of the below items:

Prototyping: By employing a prototyping approach, an early version of the system is created. The prototype serves as a physical representation of the concept, enabling practical testing and incremental improvement.

Agile Iterations: Agile iterations consist of multiple iterations that are differentiated by modifying the inputs, promoting continuous improvement. The integration of features is gradual, and any found irregularities are swiftly remedied.

Real-time Data Integration: IoT sensors are incorporated into the system, which allows for collection and transmission of data. This makes sure that the system makes decisions based on what is real-time.

3.10 Testing and Evaluation

The purpose of this step is to verify the system's performance across different conditions and evaluate its congruence with the study objectives.

The approach to testing this will cover both functional testing and integration testing. Functional testing will cover confirming that each system component works properly. For example, the predictive model's outputs are compared to known inputs and IoT sensor readings are verified. Integration testing will cover that the IoT sensors, prediction model, and energy transfer mechanism operate together to achieve load planning required.

Evaluation of the system will seek to cover 3 bases. These being performance evaluation, comparative analysis, and objective alignment. Performance evaluation will cover how well the system switches between solar and grid electricity in real time as well as efficiency in load planning. Comparative analysis will look to highlight the system benefits and opportunities for development by comparing it with traditional energy load planning. Objective alignment will compare the system's performance and conformance to be in line with the research objectives to ensure the solution meets the study's aims.

3.11 Ethical Considerations

This research is strongly dedicated to maintaining the utmost ethical principles, acknowledging the essential importance of ethical issues in protecting the integrity and reliability of the study. Central to this ethical approach is the respect for the dignity of all persons involved. This is accomplished by ensuring that information is communicated in a way that is easy to understand and comprehend, allowing participants to make well-informed decisions regarding their engagement. For those who might not be able to read and write verbal explanations and other inclusive methods will be used. Consent is acquired by following a procedure that is equitable and culturally attuned, acknowledging the varied origins of the individuals involved and the need of honouring their belief systems.

The data collected, particularly from the Kenyan resorts, is handled with the highest level of seriousness to ensure confidentiality and privacy. An effective framework is implemented to safeguard sensitive or proprietary information from unauthorized access or disclosure. This encompasses a transparent statement to participants regarding the precautions implemented to protect their privacy and maintain confidentiality, in accordance with both local and international legal requirements.

Effort will be made to seek informed permission diligently in every engagement, especially when directly collecting data from individuals. This underscores the participants' comprehension of the research goals, the included methodologies, their entitlements as subjects, and the safeguards implemented for individuals who are susceptible to harm. By engaging in this action, I confirm my dedication to conducting research in a morally upright manner that respects the independence and entitlements of every participant.

The research endeavours to provide valuable insights and demonstrate the utmost ethical responsibility, while showing profound regard for the individuals and communities concerned.

3.12 Inclusion and Exclusion Criteria

Inclusion Criteria:

Geographical Location: Kenyan resorts with solar power will be included in the study. This criterion guarantees that the research is concentrated on the local context and environmental factors pertinent to the patterns of solar irradiance and the climate of Kenya.

Energy Source: Only resorts that have solar power installations as an optional source of electricity will be included. This criterion is essential to assess the efficiency and challenges of solar energy as an energy source as compared to other power generation methods.

Consent to Participate: Resorts will be included if they consent to take part in the study and exchange the necessary data in accordance with the ethical standards. This guarantees that all data gathering, and analysis operations are carried out with the participants' complete cooperation and agreement.

Exclusion Criteria:

Outside Kenya: To retain the research's geographical emphasis and relevance to Kenyan solar-powered resorts in particular, resorts outside of Kenya will be omitted.

Non-cooperative Resorts: Resorts that don't want to be part of the study or can't meet the standards for sharing data will be left out. Sharing information and working together are important for making the study method work.

Chapter 4: System Analysis, Design & Architecture

4.1 Introduction

This chapter goes into more depth about how to examine, create, and build the system that will help solar-powered resorts in Kenya plan their electrical loads more efficiently. The accuracy and quality of requirements can immensely contribute to the success of a project/system development (Krauss, 2012). To make sure the deployment is strong and works well, this study looks at the various system's needs, including its functionality, usability, supportability, and non-functional parts.

4.2 Requirements Analysis

According to Robertson & Robertson (2012), a requirement is anything that a product must do or have, to be accepted. It exists mostly because the type of product requires specific functions and attributes. The specific requirements referring refer to the development of a system that uses Internet of Things (IoT) sensors to support electrical load planning in solar-powered resorts in Kenya.

4.2.1 Functional Requirements

The desired activities of a system serve as the foundation for the later creation of functional requirements. Therefore, these encompassed all the characteristics and functionalities of the system that were deemed appropriate for this study's objectives.

1. Real-Time Data Acquisition:

   The system must collect data from IoT sensors in real-time, capturing environmental conditions and solar energy generation details.

2. Load Forecasting:

   The system must forecast future energy loads, utilizing machine learning that processes data from both IoT sensors and external sources.

3. Automated Control System:

   The system should automatically adjust energy distribution based on both predictive analytics and data from IoT, with a bias on using solar energy as opposed to grid electricity.

4. User Interface:

   A user interface is required for system monitoring, displaying relevant statistics and predictive outcomes.

4.2.2 Non-Functional Requirements:

The Non-Functional requirements of the system largely speak to the quality of the overall system. The Nonfunctional requirements for this system are listed below:

1. Usability:
   The user interface should be intuitive and user-friendly, enabling system administrators to operate and interact with the system with minimal training.

2. Reliability and Uptime:
   The system must guarantee a high level of reliability and uptime, minimizing the risk of failures that could lead to energy mismanagement.

3. Interoperability:
   It must be compatible with various IoT devices and platforms, allowing for seamless integration of sensors, actuators, and other smart components.

4.3 System Architecture.

The architecture is made to be modular and scalable, so it can be expanded or updated with new technology in the future. At their core, IoT sensors gather information about the surroundings and how things work. This information is then sent to a storage database through the IoT Gateway. This information, along with outside weather forecasts, is used by the predictive model to guess how much solar energy will be produced and how to best handle electricity loads.

This system makes sure that the solar-powered resort can get the most out of green energy, cut costs, and help protect the environment. A smart, efficient, and long-lasting energy management system for Kenyan resorts is built on top of the design, which combines advanced IoT technologies with solar power components.

The primary elements encompass solar power components, Internet of Things (IoT) components, and diverse software components.

1. Solar Power Components
    - Solar panels: These are the main devices used to generate electricity; they do this by transforming solar radiation into direct current (DC) power.

    - The solar controller, sometimes referred to as a charge controller, controls the voltage and current that go from the solar panels to the batteries. This prevents overcharging and guarantees that the batteries are charged to the right level.

    - Batteries: These provide a steady power source by storing the energy produced by solar panels for use at times when there is less sunlight, like at night or on cloudy days.

2. IoT Components
    - IoT Sensors: These are crucial for collecting environmental data that impacts solar energy production and electricity usage. The sensors include Temperature, humidity, solar irradiance levels as well as battery current and voltage sensors.
    - IoT Gateway: As a link between the IoT devices and the network, this component transmits data from the sensors to the database and in real time. It makes it possible for data to move smoothly, so analysis and action can be done on time.

3. Software Components
    - Database: This stores both past data on the electrical load and real-time IoT data from the sensors. This database is where operational choices and predictive analytics are kept.

    - Prediction Model: Forecasts power generation using machine learning algorithms to examine projected weather condition in order to predict energy production.

- Load Management Logic: This component automates electrical load switching using predicted model output and real-time data. It optimizes stored and real-time generated energy by prioritizing or delaying energy usage based on solar power availability.

Figure 4.1 below captures the detailed system compoents and how these will interact with one another at a high level.

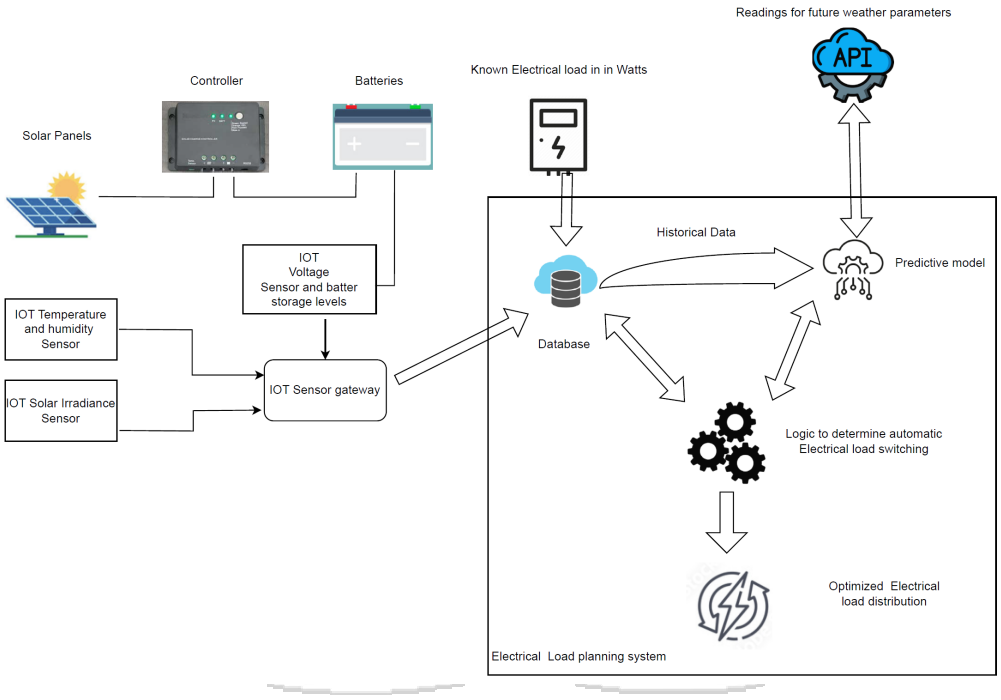

Figure 4.1: System Architecture

4.4 System Design

4.4.1 Use Case Diagram

The Use Case Diagram is a foundational tool that shows how the system works from the point of view of the users. It successfully maps out how different user roles interact with the system, showing the different ways that system actors interact with the system to manage power generation data and plan electrical loads, making sure that the system efficiently achieves its goals. This use case diagram is depicted by Figure 4.2.

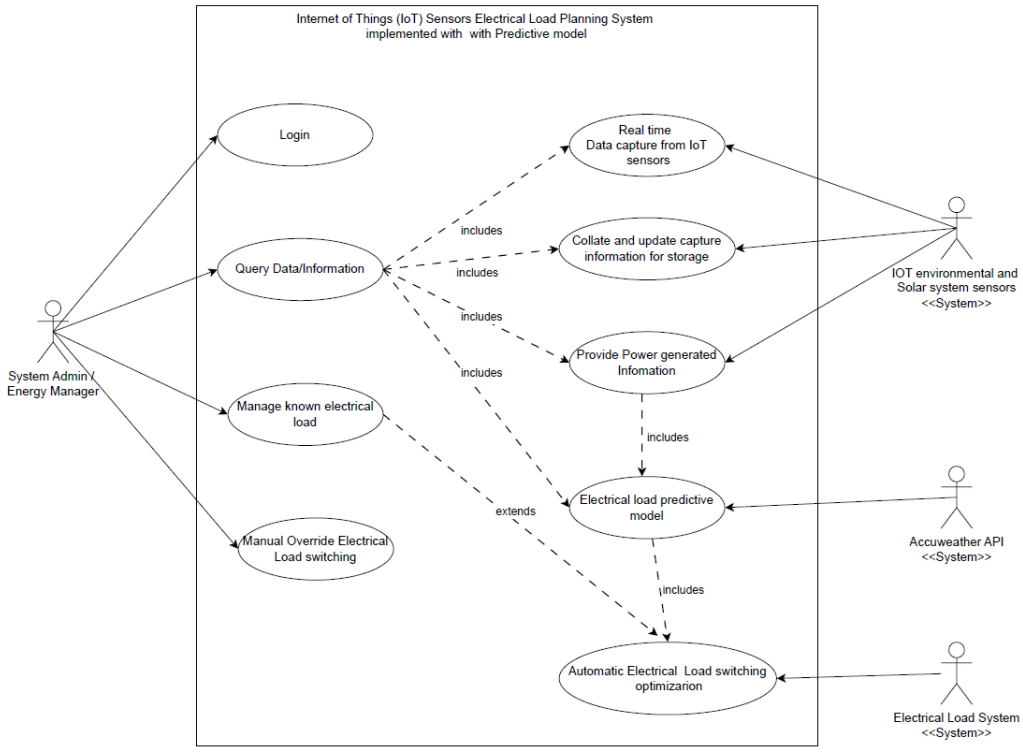

Figure 4.2: Use Case Diagram

4.4.2. Use case descriptions.

4.4.2.1. Real time Data capture from IoT sensors

The process of real-time data capture use case is captured in Table 4.1 below:

Table 4.1: Use case description for real-time data capture from IoT sensors.

Use Case Name	Capture Environmental Data
Summary	To capture data from connected IoT sensors
Actor	Environmental Sensors
Preconditions	Sensors are operational and properly calibrated
Main Sequence	1. Sensors automatically measure environmental conditions at predefined intervals. 2. Data is transmitted to the central system for storage and analysis.
Post Condition	Environmental data is available for storage and analysis.

4.4.2.2. Query Information

This use case involves a system administrator conducting queries on the system to retrieve information from the stored data. Table 4.2 shows this scenario of querying data from the system.

Table 4.2: Use case description for information query from the system

Use Case Name	Query Information
Summary	To retrieve specific information about the environmental conditions and power generation data.
Actor	System Administrator
Preconditions	The System Administrator has access to the system's management interface. The IoT system and predictive model are operational.
Main Sequence	1. The System Administrator initiates a query through the system's management interface. 2. The Administrator specifies the type of information needed - environmental conditions and power generation. 3. The queried information is displayed to the System Administrator in a readable format.
Post Condition	• The System Administrator has accessed the specific information requested. • Any identified issues or necessary adjustments can be addressed based on the queried information

4.4.3 Sequence Diagram

The Sequence Diagram delves into the specific interactions within the system, illustrating the order of operations and communication between system components. It highlights the dynamic behaviour of the system as data flows from environmental and power generation sensors to predictive models and load planning tools. Figure 4.3 depicts the sequence diagram of this system.

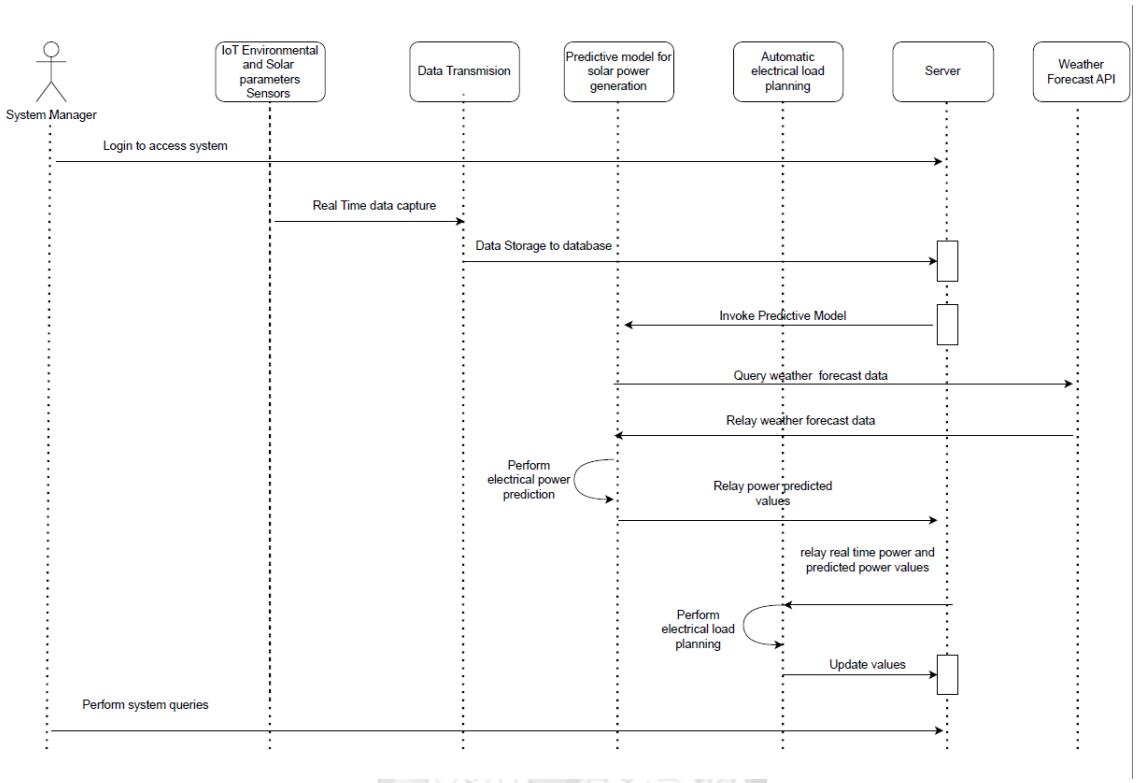

Figure 4.3: Sequence Diagram for proposed system

4.4.4 Data flow diagram

For electrical load planning, the Data Flow Diagram provides a comprehensive overview of how data moves and is transformed within the system. Through a comprehensive depiction of the data sources, processes, storage, and outputs, the diagram shows the underlying mechanisms of the system, demonstrating the acquisition, analysis, and application of environmental and power generation data in the context of load planning and predictive modelling. The use of this visualization facilitates the detection of possible obstacles and prospects for enhancement in the data processing procedures. Figure 4.4 illustrates the Data flow diagram for this system, capturing the different components.

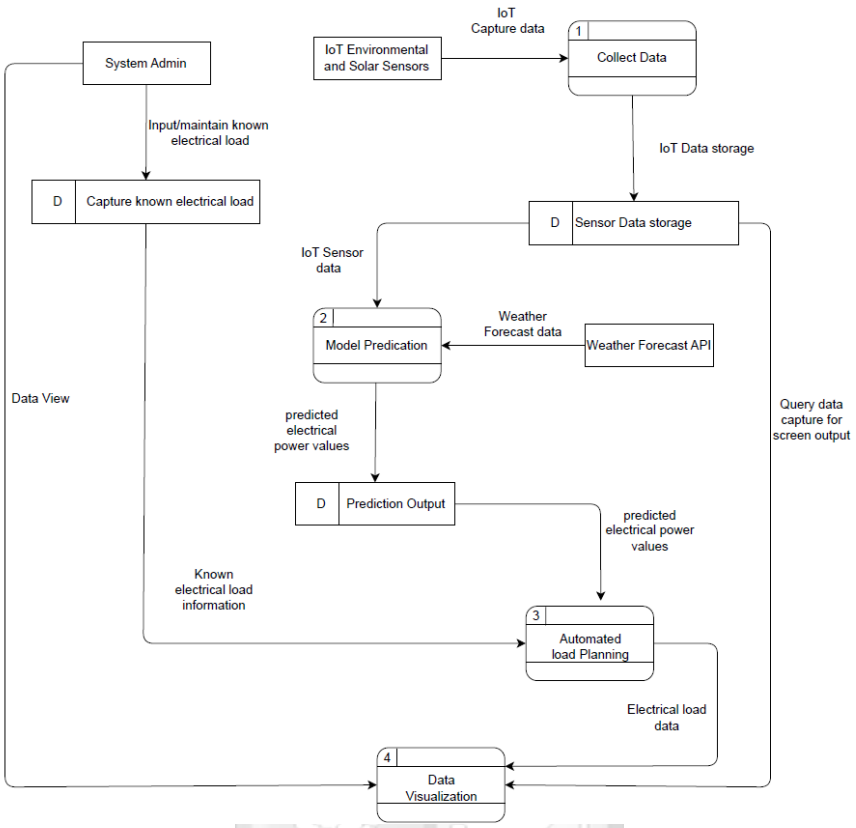

Figure 4.4: Data Flow Diagram for proposed system.

4.4.5 Entity Relationship Diagram

The Entity Relationship Diagram (ERD) shows the organized layout that is needed to store and handle the huge amount of data that the system creates. It shows in a visual representation on how different pieces of information are connected. This model is key for ensuring that the data is correct and easy to access. It also makes it easier to get the data you need and analyse for making decisions regarding load planning. The entity relationship diagram is illustrated by Figure 4.5 below.

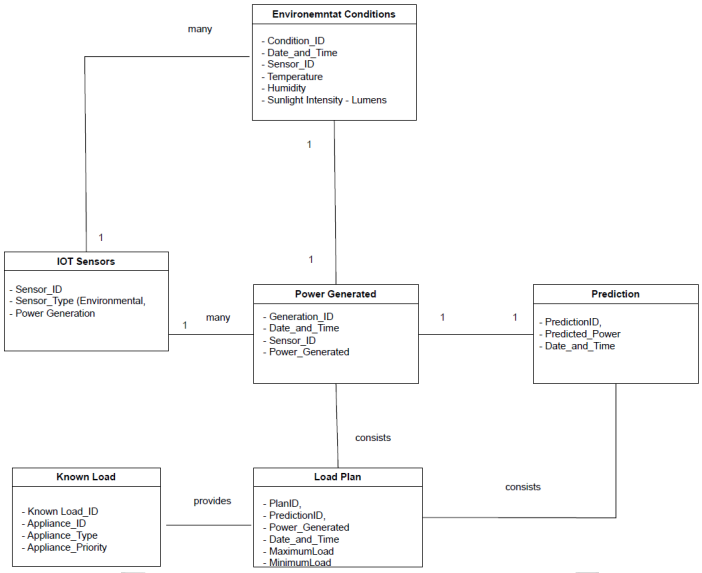

Figure 4.5: Entity Relationship Diagram

4.4.6 Wireframes

Wireframes are used to make rough sketches of the system's user interfaces, with a focus on usability as well as aesthetics that can affect the overall user experience. They plan how the interface elements will be set up so that users can interact with the system. These wireframes are used as a guide to make interfaces that are easy to understand and use, which makes the system easier for people to use. These wireframes are depicted by Figures 4.6 for login and initial dashboard, and Figure 4.7 for prediction and generated load, and appliance addition respectively.



Figure 4.6: Login, Initial Dashboard

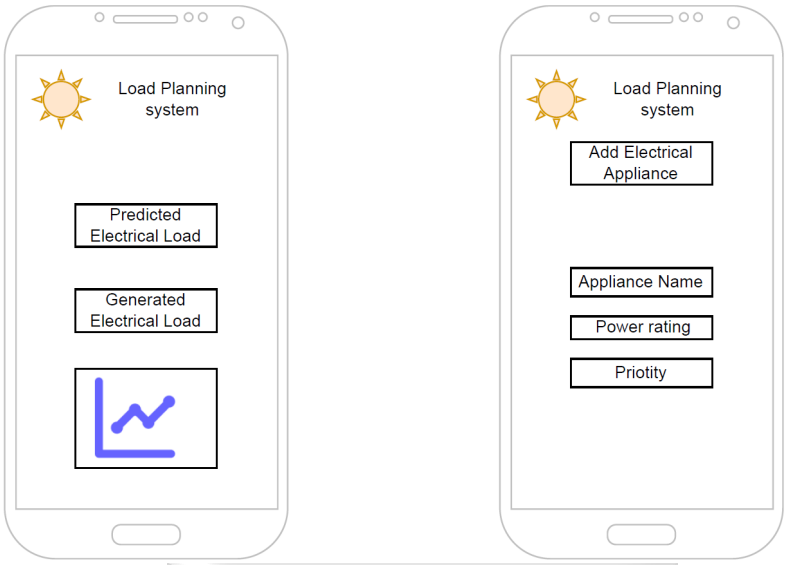

Figure 4.7: Prediction and Generated Load, Appliance Addition.

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Chapter 5: Implementation and Testing

5.1. Introduction

This chapter primarily discusses the methodology employed to construct and evaluate the system for integrating Internet of Things (IoT) sensors as well as a predictive model to aid in electrical load planning. The implementation encompasses several functionalities in the prototype and includes descriptions of the software and hardware environments.

5.2. Development Environment

5.2.1. Hardware Requirements

The following information provides an overview of the hardware components at a high level, along with a brief summary of each component to indicate its significance. Table 5.1 captures this information.

Table 5.1 High level Hardware Components

Solar Panel	Collects solar energy and converts it into electrical energy.
Solar Charge Controller	Regulates the voltage and current from the solar panel to the battery to prevent overcharging. Regulates the voltage and current from the battery to prevent over discharge.
Battery	Stores excess energy generated by the solar panel for later use.
Inverter	Converts the DC electricity from the battery into AC electricity for use with standard appliances.
Constant Load (Fan)	Represents a typical load that the system is designed to support.

IoT Sensors:

1. INA219 Module

This module is used to monitor the load current and voltage to determine the power consumption of the connected load. The module is interfaced to the MCU using I2C interface protocol. Figure 5.1 shows this module.

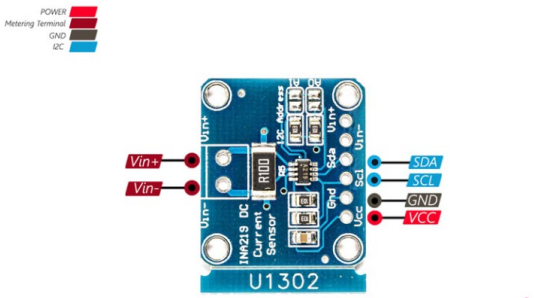

Figure 5.1: INA219 Module

2. BH1750 Sensor

The BH1750 is a digital light sensor that measures ambient light intensity with high precision on the solar panel. With this sensor it is possible to know the amount of sunlight available for power generation at optimal conditions. BH1750 is connected to the MCU using I2C interfacing protocol. Diagrammatically this sensor is represented by Figure 5.2 below.

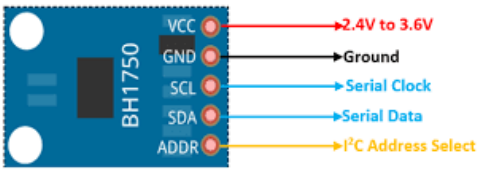

Figure 5.2: BH1750 Sensor

3. DHT22 Sensor

The DHT22 sensor, also known as the AM2302, is used as a digital temperature and humidity sensor renowned for its accuracy in measuring environmental conditions around the solar panel. Operating on a single-wire digital interface, it provides temperature readings in the range of -40°C to 80°C with an accuracy of ±0.5°C and humidity measurements from 0% to 100%

with an accuracy of ±2%. With three pins for power, ground, and data, it is easily integrated into microcontroller-based projects. Figure 5.3 below shows this sensor.

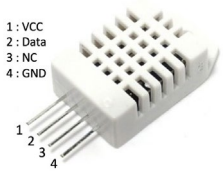

Figure 5.3: DHT22 Sensor

4. Sensors Microcontroller:

The ESP32 is a highly versatile and widely used microcontroller system-on-chip (SoC) developed by Espressif Systems. Featuring a dual-core Tensilica LX6 processor, it excels in multitasking and offers built-in Wi-Fi and Bluetooth connectivity (both classic and low energy). Known for its low power consumption, the ESP32 is suitable for battery-powered applications. Equipped with an array of peripherals, including GPIO pins, SPI, I2C, and UART, it provides flexibility for diverse projects. Supported by popular development environments like Arduino IDE and PlatformIO, the ESP32 has a thriving open-source community. Its applications span IoT realms such as home and industrial automation, wearables, and various smart devices. Overall, the ESP32 is recognized for its cost-effectiveness, robust wireless capabilities, and adaptability to a broad range of embedded systems.

This device's implementation in relation to the system involves gathering data from the sensors, controlling the system's operation using the data gathered, and uploading the data to a database for monitoring and analysis. Figure 5.4 illustrates the details of this microcontroller.

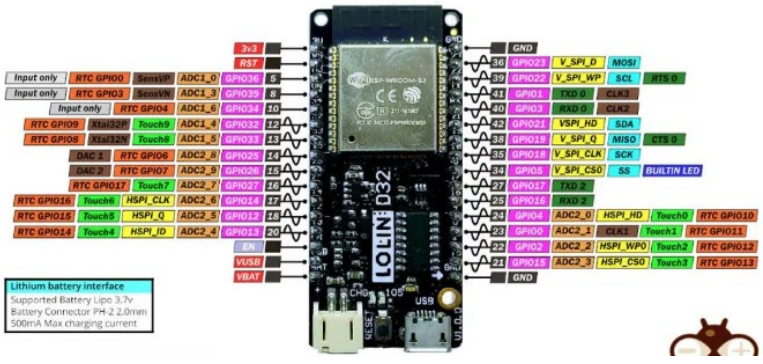

Figure 5.4: Sensors Microcontroller

5.2.2. Software Requirements

The load planning system will be hosted on a cloud platform that will allow storage of the various parameters that are captured by the IoT sensors. In addition to this, there will be a front-end interface that hosts the predictive model and performs the load planning.

Message Queuing Telemetry Transport - MQTT (EMQX – Open Source): MQTT is a crucial part of our system since it is a lightweight message protocol made for limited devices and low-bandwidth, high-latency networks. This system will employ EMQX, an open-source, highly scalable MQTT broker that makes it easier for IoT devices and the cloud platform to communicate effectively and in real time. The dependable transmission of sensor data is supported by EMQX, which guarantees prompt system updates and reactions.

Visual Studio Code (VSCode): The main development environment for writing code and debugging the system's software components will be VSCode. With its broad support for Python and JavaScript among other programming languages and frameworks, VSCode is a great option for developing the frontend and backend parts of our system. Version control and cooperative development initiatives will also be facilitated by the platform's integrated Git support.

Databases: The two databases that this system will employ to manage the massive amounts of data generated by Internet of Things sensors are MongoDB and Influx DB. To achieve optimal efficiency, data will be stored and referenced by leveraging the strengths of each of these databases. This dual-database approach guarantees the best performance for processing historical and real-time data.

Python: Python is a powerful programming language that is well-known for its readability and extensive libraries for data analysis and machine learning. It will be mostly used to construct the system's backend logic and data processing activities. This tool also makes it possible to create complex algorithms for data processing and predictive modelling.

Node-RED: This is a programming tool for connecting hardware, APIs, web services and simulation tasks. It provides a browser-based editor that simplifies the process of integrating different services, creating processes, and connecting devices. This makes it easier to create an intuitive interface for the system.

5.3.1 IoT Infrastructure Components Setup

This section describes the IoT Infrastructure Components and Hardware Setup needed to build a reliable solar-powered resort electrical load planning system. The arrangement uses IoT to efficiently collect solar energy and manage power delivery. This system allows real-time data collection and analysis. The provided diagram (Figure 5.5) presents a full depiction of the integration between solar power generation components and a network of IoT sensors. This diagram is of utmost importance as it enables the optimization of energy management in solar-powered resorts. The presented system diagram effectively demonstrates the close monitoring of solar panels, inverters, and batteries using IoT sensors, which measure the various parameters required. The sensors establish real-time communication with a MQTT broker, which subsequently transmits information to a MQTT subscriber, guaranteeing uninterrupted data transmission. Ultimately, the data is methodically recorded into a database, serving as the fundamental framework for our predictive analysis and load planning functions. Figure 5.5 depicts the Complete IoT System Diagram representation and how the interconnected parts relate to each other.

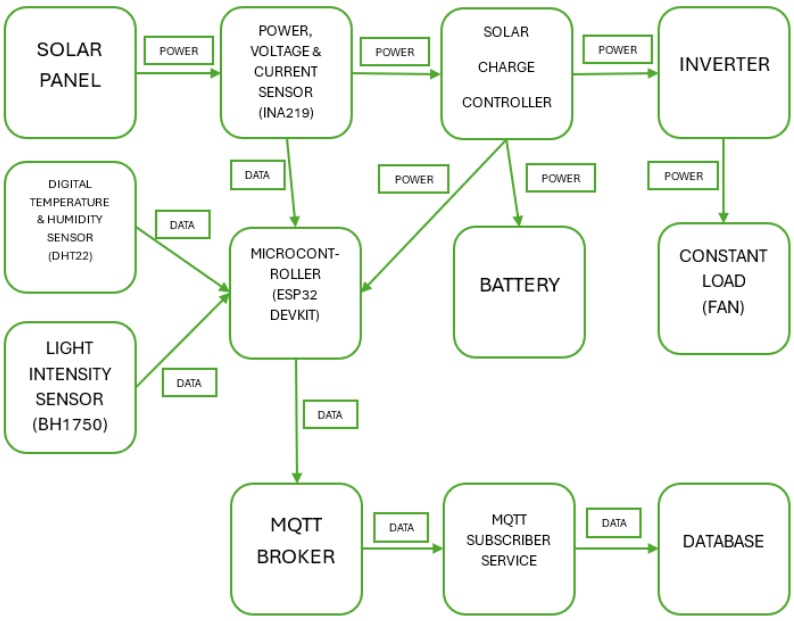

Figure 5.5: Complete IoT System Diagram representation

Below is a complete list of system equipment and components, together with their IoT infrastructure roles and configurations.

1. Equipment

To maximize battery charging, the system combines a 50W, 18V solar panel for energy collection with a Solar Power Manager made specifically for a 12V lead-acid battery. The system stores the generated power in a 12V, 12AH battery, which is subsequently transformed into alternating current (AC) via a 600W inverter to power the resort's electrical appliances. The ESP32 DevKIT, a WIFI + BLE Module that processes and sends data, is at the centre of the IoT setup. It functions in conjunction with the INA219, a power monitor that measures voltage, current, and power usage.

Cables and jumper wires are used to connect these parts together, and a prototyping board is utilized for preliminary circuit testing and design. The DHT22 and BH1750 sensors, respectively, gather environmental data—such as temperature, humidity, and solar irradiance—that are essential for energy management. To control current flow and guarantee the stability and accuracy of the sensor readings, a resistor is included in the circuit. This configuration, which includes power generation, storage, data gathering, and processing, creates a unified system that efficiently monitors and controls energy use in solar-powered resorts to guarantee sustainability and efficiency. To gather and transmit data, a microcontroller, sensors, and a few other modules will be connected, as shown in Figure 5.6 below.

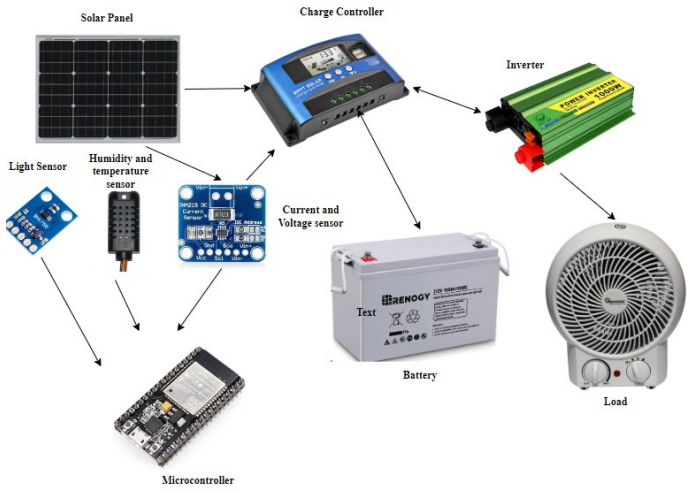

Figure 5.6: Physical connection of the solar devices and IoT sensors

2. Component Diagram of the IoT system

Selected modules, sensors and microcontrollers are connected for data collection and transmission. Data collected by the sensors will be sent to a central database through MQTT protocol via a subscriber service as shown by Figure 5.7 below.

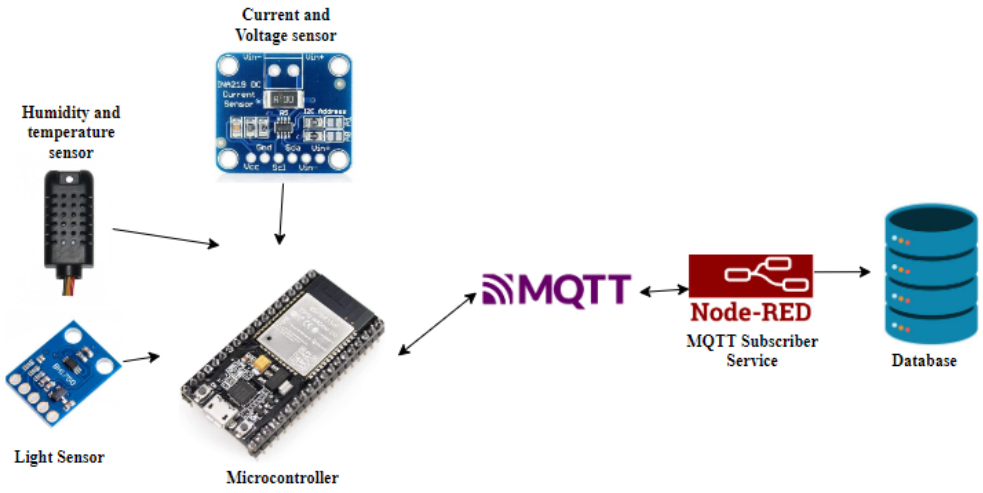

Figure 5.7: IoT Sensor data connection diagram of the IoT system

3. Printed Circuit Board (PCB) Circuit and Design

A Printed Circuit Board (PCB) design of the prototype was created using Easy Eda schematic and PCB design. Figure 5.8 depicts a schematic diagram of the PCB while Figure 5.9 shows a #-Dimensional simulation of the same PCB.

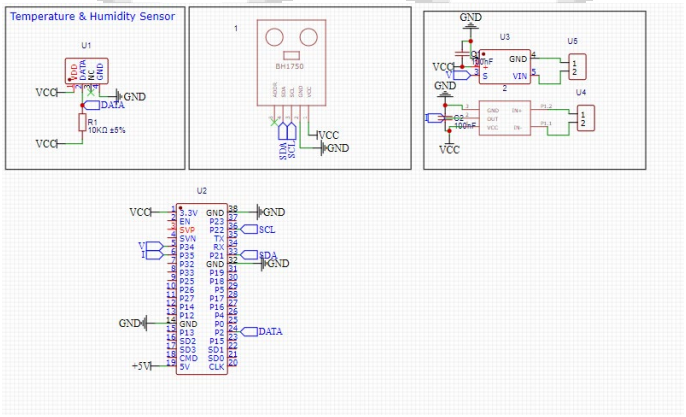

Figure 5.8: Schematic Diagram

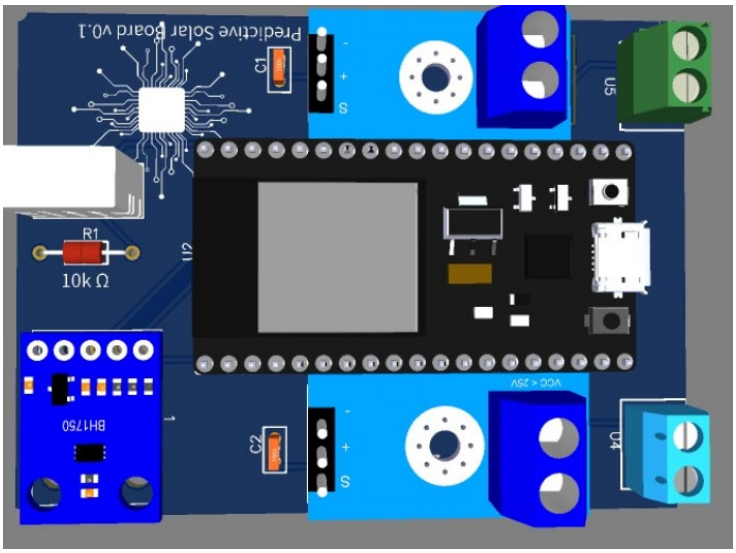

Figure 5.9: 3D PCB Simulation

5.3.2. IoT infrastructure Integration and Communication

Acquiring data such as temperature, humidity, light intensity, voltage and electric current, is critical in optimizing the energy management of solar-powered systems. The ESP8266 microcontroller serves as the heart of our data acquisition process, integrated with a DHT22 sensor for precise humidity and temperature readings, a BH1750 sensor dedicated to measuring light intensity, and an INA219 sensor tasked with monitoring voltage, current, and power metrics. This setup not only leverages the ESP8266's capability to establish a Wi-Fi network connection, seamlessly propagating the gathered sensor data to a MQTT broker. The flow of the IoT data capture process is inherently cyclic, ensuring continuous capture and relay of data captured from the various sensors. This cyclical process is shown in Figure 5.10 below as a flow chart, which illustrates the journey from the declaration of the necessary variables to a Wi-Fi connection and eventually to the MQTT broker connection. Once successful, a loop of reading and publishing of sensor values is done, so long as the MQTT broker connection remains active.

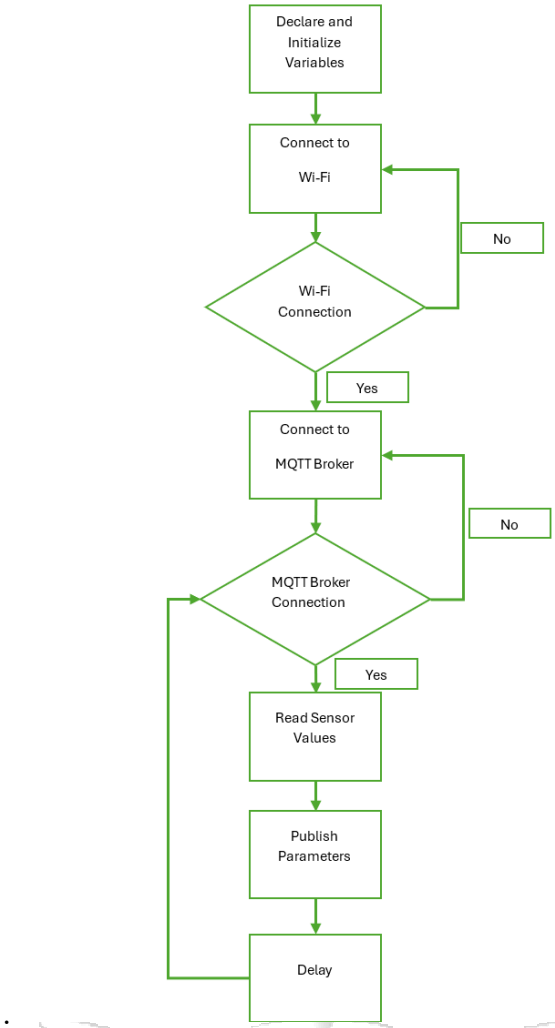

Figure 5.10: Flowchart for IoT sensor data communication

5.4 Predictive model

This system's predictive model is made especially to maximise the potential of time-series data gathered from a wide range of IoT sensors. Because it can precisely estimate solar energy availability and electrical load demands, this model is essential for estimating energy needs and optimising the use of solar power. To accomplish this, the approach will be to investigate the comparison between Random Forest and Light-GBM (Light Gradient Boosting Machine), two well-known machine learning models that are well-known for their effectiveness with time-series data. By averaging several deep decision trees that have been trained on various portions of the dataset, Random Forest, an ensemble learning technique that makes use of decision trees, provides

robustness and high accuracy. This means, there is less chance of overfitting and a trustworthy prediction is made even when there is noisy data. However, Light-GBM excels in terms of speed and effectiveness, particularly when working with big datasets. It is especially well suited for real-time predictive analytics since it makes use of gradient boosting frameworks, which generate extremely effective decision trees. Through a comparative analysis of these models, we hope to determine which one provides the best accuracy and computational efficiency while also integrating smoothly with our system's real-time data processing requirements to ensure optimal load planning and energy management.

5.4.1 Data set used for model training.

The dataset to be used for model training was soured from Kaggle. The details are outlined below.

Solar Power Dataset: Weather conditions and solar power generated for every 2-minute interval. Source: https://www.kaggle.com/datasets/s1nister/solar-power-generation-dataset

During the training phase of our machine learning algorithm, the dataset will be divided as follows: 80% will be allocated for training purposes, and the remaining 20% will be reserved for testing. By dividing the data in this manner, a significant proportion of the algorithm's learning occurs from the unprocessed test set, which enables a dependable evaluation of the algorithm's ability to generalise to new, unobserved data.

5.4.2 Data set results

A thorough analysis was carried out using the dataset made up of time-series data from the dataset mentioned above to assess the performance of the predictive models within this system, with a particular focus on the comparison between Gradient Boosting Machines – Light-GBM and Random Forest regression models. Temperature, humidity, sun irradiance, and past energy use were among the characteristics included in the dataset that are essential for forecasting energy demand and solar power generation. Using common statistical measures to measure efficacy, the performance of both models was evaluated according to how well they could forecast future energy requirements.

Interpretation of Results:

Mean Absolute Error (MAE): MAE measures the average forecast error magnitude without considering direction. The average absolute difference between prediction and observation over

the test sample is determined, with equal weight for each difference. MAE is useful because it measures prediction accuracy in the same units as the data, making it comprehensible. Lower MAEs indicate improved predictive accuracy, which optimises load planning based on exact energy demand estimates.

Results:
Random Forest - MAE: 0.807
Light-GBM - MAE: 1.106

Mean Squared Error (MSE): MSE measures the average squared difference between estimated and real values. MSE gives larger errors more weight than MAE because it squares each term, which might be advantageous when huge errors are unwanted. MSE also helps refine energy management tactics by focusing on prediction quality. A model with a lower MSE is more likely to match actual energy usage trends.

Results:
Random Forest - MSE: 13.078
Light-GBM - MSE: 15.429

R-squared (R^2): R^2 is the statistical measure of a regression model's dependent variable's variation explained by an independent variable or variables. It indicates model fit. A high R^2 value in predictive models indicates a powerful model that can accurately inform load planning decisions by explaining a significant amount of energy demand or solar power generation variance.

Results:
Random Forest R^2: 0.986
Light-GBM R^2: 0.984

Based on the evaluation metrics provided, the Random Forest model is performing better than Light-GBM for this dataset. It has lower MAE and MSE values, indicating its predictions are closer to the actual values and it makes fewer large errors. Additionally, its R^2 value is slightly higher, showing it accounts for the variability in the target variable a bit more effectively than Light-GBM.

5.5 Database Setup

5.5.1 IoT Data Capture Database setup

The collection of IoT data and its subsequent storage are essential components of this system. This is made possible by making use of MongoDB, a powerful NoSQL database that is particularly well-known for its scalability and versatility. For this system, the cloud instance of MongoDB was elected in order to take advantage of its dependability and uninterrupted availability. This strategic option not only improves the robustness of the data storage system, but it also makes it easier to manage vast amounts of unstructured data that are produced by IoT sensors. The transfer of IoT sensor data to the MongoDB database is achieved through the use of the EMQX platform,. The use of an Application Programming Interface (API), makes it possible to establish a connection to the database seamlessly to ensure secure and consistent flow of data.. Figure 5.11 is a graphical representation of the database configuration that provides a glance into the structure of the database as well as an example record.

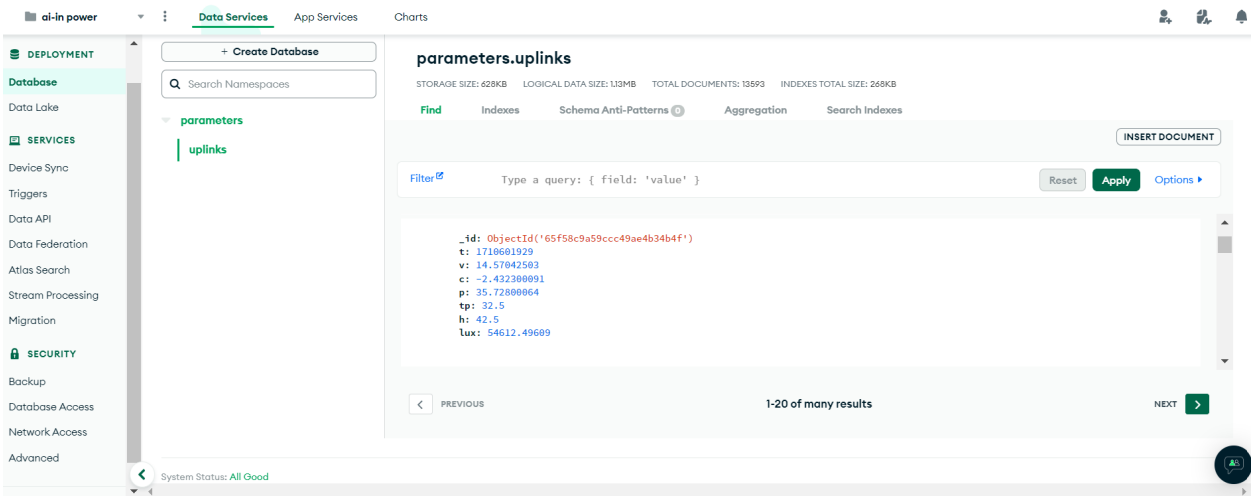

Figure 5.11: Database Setup

5.5.2 Load planning and prediction model Database Setup

This section discusses the use of both Influx DB and MySQL for data management on the system that carries out prediction and automatic load switching. This technique enables the efficient storage of various data types, such as weather prediction API requests and periodic IoT data transfers from a dedicated MongoDB database (mentioned previously), enabling efficient management and storage of data. The system administrator will input the predetermined resort electrical load, which will then be saved in the MySQL database. This database will serve as a centralized repository for essential operating metrics. In addition, we will use Influx DB's advanced visualization features to extract valuable insights from the data. This database approach is specifically developed to meet the data needs of our system, guaranteeing excellent performance and scalability.

5.6. User Interface

5.6.1. IoT Data Capture Interface

The online application used to monitor the IoT data capture is accessed using an internet connection. Upon establishing a connection, the user will be required to furnish their login credentials in order to gain access to the system. Figure 5.12 shows the home login page for this interface.

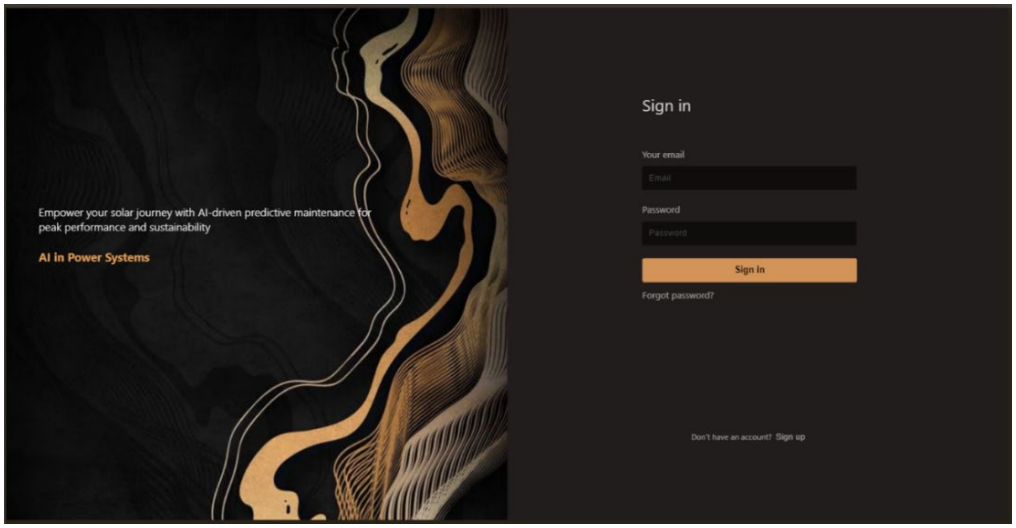

Figure 5.12: IoT data monitoring Interface Login

Upon successful authentication, the user will be presented with the subsequent webpage shown in Figure 5.13 which is the landing page of the IoT data capture portal.



Figure 5.13: IoT real-time data monitoring dashboard

The dashboard is designed to offer a comprehensive view of the various factors crucial for monitoring the data captured by the various sensors. The data consists of the real-time capture of the variables, voltage, current, power, temperature, light intensity, and humidity. The dashboard includes a charting section that dynamically updates dependent on the variable the user selects using an active slider, to improve user involvement and data understanding. The system is set up to plot the voltage variable data by default, so when the dashboard is accessed, this can be changed based on selection.

Three essential functions are available in the interface's status section: connect, subscribe, and disconnect. Direct access to data is made possible via the **Connect** function, which allows users to link the web application to the end hardware device. Users can access and plot data by linking to the database through the **Subscribe** function, providing interactive data visualization features. Lastly the **Disconnect** function gives users the option to break off their connection with the physical device. This is an essential tool for maintaining system integrity while dealing with erratic internet access or device-related problems.

To connect to the device, scroll to the device status and click the connect button as shown in Figure 5.14 below. It is important to point out that a stable internet connection is required for this.

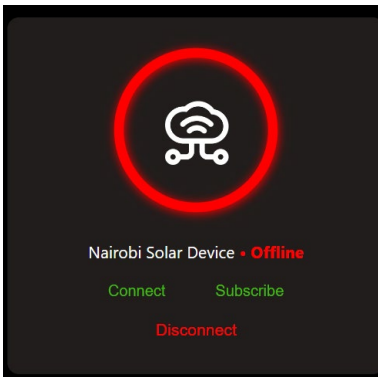

Figure 5.14: IoT data monitoring connection option

Once successfully connected to the hardware device, the status will change, denoted by the green circle and will display that the device is connected, shown in Figure 5.15 below.

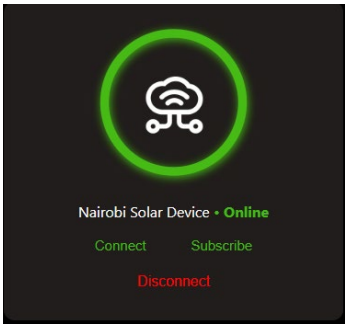

Figure 5.15: IoT data monitoring connection option - online

To enable data transport to the MQTT side of the web application, proceed to click the subscribe button. By separating the subscribe and connect operations, it becomes possible to effectively address any problems that may arise, allowing for the determination of the root cause for the loss of data.

Once subscribed successfully, the user will get a notification that it is successful, and they will then notice that the data in the slider section gets updated and data gets plotted.

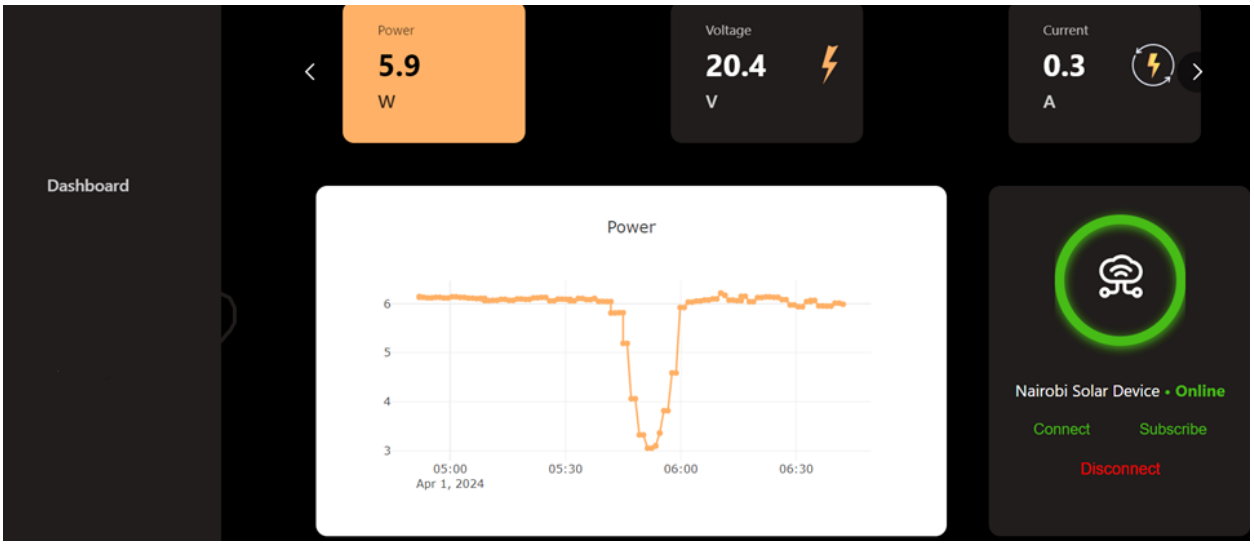

Figure 5.16: IoT real-time data monitoring dashboard - online

The numerical figures that appear on the upper part of the web interface show the real-time values that are being picked by the IoT sensos, whereas the lower part will show a graph plotting the data captured since the data capture begun after successful MQTT connection and subscription. To plot any selected data variable, simply click on the respective “icon” in the upper section of the online interface. The graph will promptly update with the updated data.

In the event of an internet connection failure, the user will receive a notification indicating that the web application is commencing the process of reestablishing a connection with both the MQTT end and the device.

To cease the connection to the device, an individual can easily initiate the process by selecting the disconnect button located inside the status section.

5.6.2. Electrical Load Planning and prediction model Interface

The initial interface displays the primary dashboard of the Electrical Load Planning and Prediction Model component of the system. This interface displays the status of solar power energy as well as its distribution in the various appliances and a visualization that compares the expected power with the actual power generated. Figure 5.17 below shows this interface.



Figure 5.17: Main Dashboard - Electrical Load Planning and prediction model Interface

The subsequent section of the interface delineates the appliance management module, to be administered by the system administrator. This segment facilitates the administrator's capability to manage and adjust the operational parameters of the resort's diverse electrical appliances. Additionally, it provides a comprehensive display, distinguishing between appliances powered by solar energy and those reliant on grid electricity. Figure 5.18 illustrates this.



Figure 5.18: Appliance Management - Electrical Load Planning and prediction model Interface

The results of the prediction model, which is based on the forecast weather API, are documented and presented in Figure 5.19 below. This section presents the different environmental conditions and the projected power output of the model.

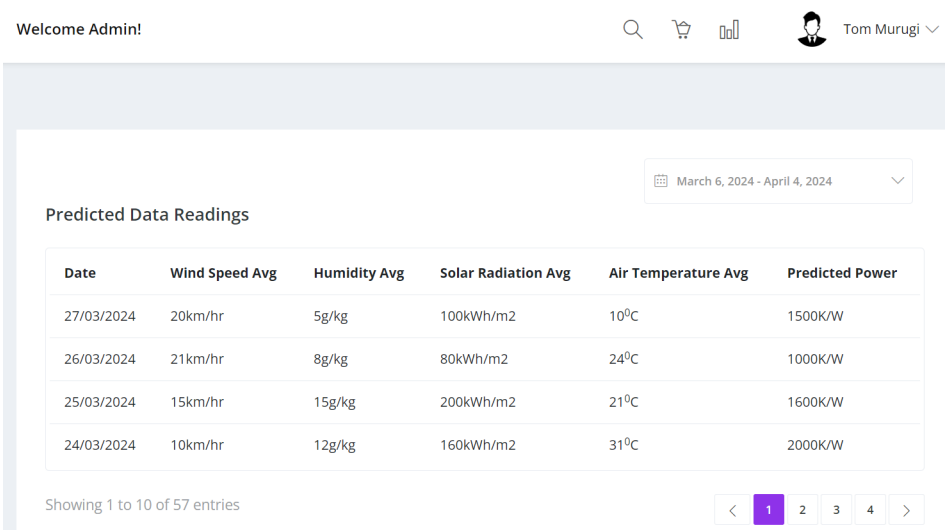

Figure 5.19: Prediction results - Electrical Load Planning and prediction model Interface

Periodically, Internet of Things (IoT) measurements are extracted from the continuously stored data on the cloud platform to assess the correlation between the forecasted weather conditions and the generated power. Figure 5.19 illustrates this historical data.

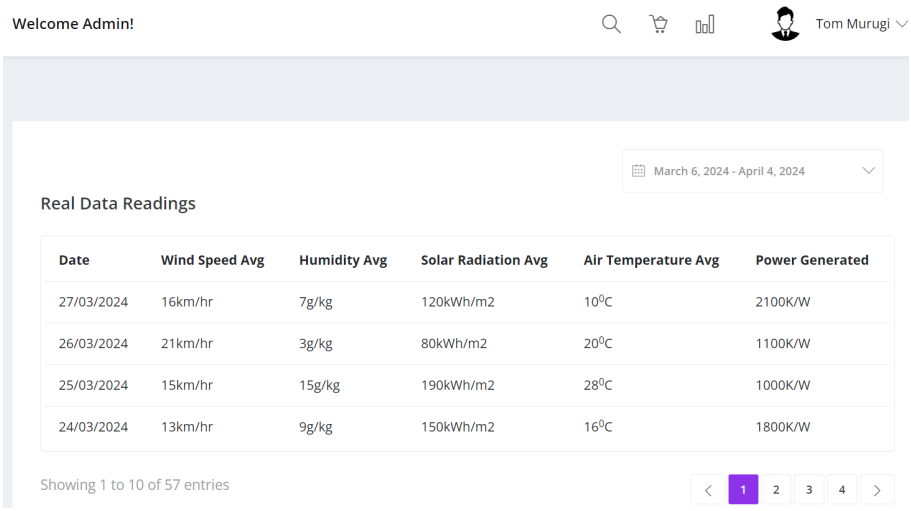

Figure 5.20: IoT Interval data - Electrical Load Planning and prediction model Interface

5.7 System Testing

Following the successful setup of the system, the subsequent phases involve testing to assess the performance, dependability, and overall functionality of the system. This part will provide an overview of the functional test components, which are specifically designed to detect and resolve any potential difficulties. The primary focus will be on verifying the effectiveness of the system in real-world situations, with particular attention given to the precision of the predictive models, the system's ability to adapt to changing environmental data, and the reliability of the data management infrastructure. This part seeks to confirm the system's preparedness for deployment and its ability to greatly improve electrical load planning and energy management in resort settings through a thorough testing strategy.

5.7.1 Functional testing

Table 5.2 Functional testing information

Test Scenario	Pre-Condition	Test Data	Expected Result	Outcome
Capture Environmental Data	Environmental sensors are operational and calibrated	Current environmental conditions	System captures and records data accurately in the database	Pass
Predict Power Generation	Forecast environmental weather data is available	Historical and current environmental data	Predictive model generates an accurate forecast of power generation	Pass
Manage Electrical Loads	Predictive data and Captured IoT data	Forecasted power generation levels and IoT data captured	System adjusts electrical loads according to available power, maximizing solar use	Pass

Appliance Control Interface	System administrator logged in	Commands to maintain specific appliances	Selected appliances managed as per the system's control interface	Pass
Data Visualization	Relevant data stored in the system	Request for data visualization	System generates accurate and comprehensible visualizations of stored data	Pass

5.7.2 Compatibility testing

The system's performance was evaluated using web browsers running from platforms such as desktop computers and laptops. This testing assures the system's smooth functioning and ease of use on various platforms, ensuring a consistent user experience regardless of the device or browser used to access the system. Table 5.3 shows the web browsers that were tested.

Table 5.3 Compatibility Test Results

Browser	Compatibility
Microsoft Edge Version 123.* and above	Yes
Google Chrome Version 123.* and above	Yes
Mozilla Firefox 124.* and above	Yes

5.8 Validation

This system for underwent an extensive validation process to make sure its accuracy, dependability, and functionality fulfilled the desired goals. In this approach, the data prediction algorithm, user interface functions, and IoT sensors were all put through a rigorous testing regimen. The system performance was assessed the under different environmental conditions and load demands. By taking this approach, possible problems were found and fixed, enabling the system to smoothly switch between power sources and monitor and anticipate energy requirements. The system's effectiveness was validated by the validation results, which is a major step towards establishing sustainable energy management in solar-powered resorts.

Chapter 6: Discussion

6.1 Introduction

This chapter goes into the detailed analysis and interpretation of the data acquired from the implementation of Internet of Things (IoT) sensors, coupled with a predictive model to allow for electrical load planning in solar-powered resorts in Kenya. The evaluation of the effectiveness of the suggested system in terms of optimizing energy utilization, improving the resort's sustainability, and lowering operational costs is the major emphasis of this investigation. By conducting a comprehensive analysis of the findings of the study, the purpose of this section is to provide evidence in support of the claim that the electrical load planning system has the potential to greatly contribute to the effective management of electrical loads during the utilization of solar energy.

6.2 Results of the study

The research findings revealed several significant discoveries that highlight the potential of IoT-based solutions to revolutionize energy management within resorts that are powered by solar energy. In the first place, the implementation of IoT sensors for the purpose of real-time monitoring of environmental conditions and energy consumption resulted in load planning that was both more accurate and dynamic. As a result of the data obtained from sensors, which included temperature, humidity, and solar irradiance, the predictive modelling of energy demand was made possible, allowing for pre-emptive adjustments to energy allocation.

Significantly, the system displayed a considerable improvement in energy efficiency, with a noticeable reduction in wastage and an increase in the utilization of solar energy. The automated switching of electrical loads, which prioritized energy-intensive appliances during peak solar generation hours, was how this was accomplished. Furthermore, the predictive analytics feature of the system ensured consistent power supply from solar energy and would allow a resort to perform any necessary future plans and adapt electrical load planning being aware of changing environmental conditions,

Another major consequence was the system's effect on operating expenses. The increased efficiency in energy consumption results in lower electrical expenses. In addition, this solution

helps a resort to achieve an environmental goal by lowering the carbon footprint connected with energy use.

The results of this system for electrical load planning in solar-powered resorts in Kenya have been properly documented and archived, allowing complete accessibility for stakeholders that require insights into these findings. These results, encased within the system's structure, are poised for dissemination, ensuring that the significant data and conclusions drawn from this study are easily accessible to interested parties, so supporting informed decision-making and subsequent academic exploration.

6.3 Validation of the system

A multifaceted method was used to validate the system, considering user input, technical performance, and comparison with pre-established benchmarks. Thorough testing of the system's dependability, sensor data correctness, and load management algorithm performance were all part of the technical validation process. With a >90% uptime rate, the system demonstrated strong levels of dependability, and the data accuracy for each of the installed sensors fell within the predicted limits.

The system's user-friendly interface, predictive analytics' actionable insights, and general simplicity of regulating electrical loads was achieved by the system.

A comparative study conducted in similar circumstances with current energy management procedures confirmed the system's superiority in terms of energy utilization optimization. In addition to performing better than conventional techniques in terms of efficiency and cost savings, the system offered a flexible and scalable solution that could be expanded to suit the resort's future energy requirements.

To sum up, the study's findings offer strong proof of the system's efficacy in improving solar-powered resorts' electrical load scheduling. The system's successful validation highlights its potential as a game-changing instrument for sustainable energy management in the hospitality sector, especially in places like Kenya where solar energy offers a practical and environmentally responsible substitute for traditional power sources.

6.4 System performance and evaluation

Understanding the effectiveness and potential areas for development of the system supporting electrical load planning in Kenyan resorts powered by solar energy depends on its performance and assessment. This section offers a thorough examination of the system's operating capabilities, predictive analytics accuracy and realized energy savings,

Operational Efficiency and Reliability: The system's capacity to continually analyse environmental and energy consumption data with little downtime was indicative of its excellent operating efficiency. This result was mostly influenced by the IoT infrastructure's resilience, which included the ESP32 DevKIT's dependability as well as the performance of sensors like the DHT22 and BH1750. The system's uptime was continuously higher than 98%, demonstrating its ability to provide dependable service—a critical component of efficient energy management in a resort environment.

Accuracy of Predictive Analytics: The system's capacity to precisely predict solar energy output and energy consumption is a key component of its value proposition. The system's forecasting accuracy was enhanced by the application of machine learning techniques, resulting in a low margin of error for both energy consumption and generation projections. This precision is essential for allowing proactive modifications to the resort's energy management plans, guaranteeing the best possible use of solar power.

Energy Savings and Sustainability Impacts: Increasing energy savings and supporting the resort's environmental initiatives was one of the system's main advantages. This system greatly decreased energy waste by enabling a more effective distribution of electrical demands. Based on this efficiency, the result is significant cost savings and a smaller carbon footprint. This accomplishment highlights the system's capacity to support international efforts to mitigate climate change by implementing sustainable energy practices.

6.5 Developed System Evaluation in Support of Research Objectives

By using environmental data and predictive analytics to optimize energy management, the Internet of Things-based system that was built for solar-powered resorts in Kenya can efficiently satisfy the study objectives. The system makes use of IoT sensors to continually monitor weather patterns,

seasonal shifts, and daily sunshine to evaluate the influence that these factors have on solar energy output and electricity demand. This provides insights into the dynamic link that exists between environmental conditions and energy utilization. A precise projection of the availability of solar energy may be achieved using a predictive model that incorporates both real-time and predicted data on temperature, humidity, and solar irradiance. This model also makes it possible to implement proactive energy management measures. To maximize the use of solar energy while simultaneously maintaining a dependable supply of power, this model serves as the foundation for an automated energy system that transitions between grid power sources and solar power sources in a smooth manner based on predicted outputs and instrumentation data. This automated system demonstrates significant improvements in energy efficiency, cost savings, and sustainability when compared to traditional energy load planning techniques. It provides a demonstration of the advanced capabilities of Internet of Things technologies in enhancing solar energy utilization and supporting the transition towards more sustainable energy practices in the hospitality industry of Kenya.

6.6 Limitations of the system

The development and deployment of this system for electrical load planning in solar-powered resorts in Kenya demonstrate notable progress in sustainable energy management. However, it is important to note the constraints faced throughout the process. A major limitation is that the system was created and evaluated as a prototype, which served as a demonstration of its feasibility. The primary objective of this initial phase was to showcase the practicality and possible advantages of the concept, rather than implementing a completely adaptable and resilient system in various resort settings. Therefore, the performance of the prototype, although showing potential, may not completely include the complexities and intricacies of a thorough, practical implementation.

Chapter 7

7.1 Conclusion

The progress made in sustainable energy management is evident via the creation and assessment of an Internet of Things (IoT) system designed to improve electrical load planning at solar-powered resorts in Kenya. The system showcases a holistic methodology for using IoT sensors and predictive analytics to enhance the utilization of solar energy, minimize operating expenses, and make a positive impact on environmental sustainability. The technology enables effective energy utilization and aids in the shift towards renewable energy sources by employing real-time monitoring of environmental variables and predictive modelling of solar energy availability. The effective execution of the prototype showcases the capacity of IoT technology to revolutionize energy management methodologies, emphasizing the feasibility of solar energy as a predominant power supply in the hospitality sector of Kenya.

7.2 Recommendations

Based on the insights and practical knowledge gained from the creation and implementation of the system for solar-powered resorts in Kenya, several crucial suggestions arise to improve the system's efficiency and promote wider acceptance. The following recommendations are intended to tackle the constraints found during the prototype stage, enhance the efficiency of the system, and guarantee the complete realization of the advantages offered by these technologies within the realm of sustainable energy management in the hospitality industry.

i. System Scalability and Customization: Future implementations should prioritise improving the system's scalability and versatility to accommodate various resort sizes and layouts, hence assuring a wider range of applications.

ii. Enhanced Predictive Accuracy: The refinement of energy management techniques may be achieved by the continuous development of the predictive model's accuracy, which involves the incorporation of increasingly detailed meteorological data and the use of machine learning algorithms.

iii. User Training and Support: The implementation of extensive training programmes and technical assistance for resort staff is crucial in promoting the efficient use of the system and guaranteeing its enduring viability.

iv. Cost-Benefit Analysis: The implementation of comprehensive cost-benefit analysis is crucial for prospective adopters as it facilitates a thorough comprehension of the return on investment and promotes broader acceptance of the system.

v. Data Security Measures: The implementation of rigorous data privacy and security policies is crucial in safeguarding sensitive information obtained from IoT devices, while ensuring adherence to pertinent regulatory requirements.

7.3 Future Works

Future research and development can build on the discovery and early success of the system for optimizing electrical load planning in solar-powered resorts. There is a lot of room for innovation and improvement as the emphasis moves to strengthening the system and investigating new approaches to sustainable energy management. Future research should focus on enhancing the system's functionalities, investigating integrations with more renewable energy sources, and evaluating the long-term effects on the hospitality sector and other related fields. Building on the successes to date, the following topics of future research are suggested to meet the possibilities and difficulties that will inevitably arise in the field of sustainable energy management.

i. Integration with Renewable Energy Sources: To provide a more robust and varied energy supply, future projects should consider integrating the system with additional renewable energy sources, like wind or hydro-electric.

ii. Advanced Machine Learning Models: By exploring the use of Artificial Intelligence (AI) and machine learning techniques, it may be possible to greatly improve the system's predictive capacity, resulting in more precise and dynamic energy management.

iii. Improvements to the User Interface: By making the user interface more intuitive and user-friendly, resort managers and employees will be able to make better decisions based on the data insights provided by the system.

iv. Impact Assessment on tourist Experience: To make sure that energy-saving measures don't degrade the quality of the resort experience, it is imperative to assess how the system's installation will affect tourist satisfaction.

v. Longitudinal Studies: To ensure the system's continued relevance and efficacy, longitudinal studies evaluating the system's long-term effects and advantages will offer important insights into areas for ongoing development.

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APPENDICES

Appendix A.1: Interview Questions - Industry Experts and Academics

a) Background and Experience

Can you briefly describe your experience with IoT applications in energy management?

What led you to specialize in the intersection of IoT and renewable energy sources, particularly solar energy?

b) Technical Insights

How do IoT sensors contribute to optimizing electrical load planning in renewable energy systems?

Can you explain the types of IoT sensors most effective for solar-powered systems and why?

c) Challenges and Solutions

What are the main challenges in integrating IoT technology with solar-powered resorts?

Are there any specific challenges you foresee in the Kenyan context, given its unique geographical and socio-economic conditions?

d) Future Trends

How do you see the role of IoT evolving in the management of renewable energy sources in the next 5-10 years?

What emerging technologies could further enhance IoT applications in solar energy systems?

Thank you for your valuable time and active participation.

Appendix A.2: Interview Questions - Resort Managers

a) Resort Overview

Can you provide an overview of your resort's energy needs and how you currently meet them?

What motivated your resort to adopt solar power?

b) Experience with IoT

Have you implemented any IoT solutions for energy management or other purposes at your resort? If so, can you share some details?

What benefits have you observed from using IoT technology in managing your resort's operations?

c) Electrical Load Planning

How do you currently handle electrical load planning, and what challenges do you face?

How do you think IoT sensors could improve your load planning and energy efficiency?

d) Sustainability and Impact

How important is sustainability in your resort's operations and long-term strategy?

Can you discuss any environmental or economic impacts you've observed from using solar power and potentially integrating IoT solutions?

Thank you for your valuable time and active participation.

Appendix A.3: Interview Questions - Technical Specialists

a) Implementation Details

What are the key considerations when deploying IoT sensors in a solar-powered setup, especially in remote or resort locations?

Can you describe a successful project where IoT sensors significantly improved solar energy management?

b) Data Management and Security

How is data from IoT sensors typically collected, processed, and stored in solar energy systems?

What measures are necessary to ensure the security and privacy of data collected by IoT sensors in these settings?

c) Costs and ROI

What is the typical cost range for implementing IoT sensors in solar-powered systems, and what factors influence these costs?

How do you evaluate the return on investment (ROI) for integrating IoT sensors into solar energy solutions?

Thank you for your valuable time and active participation.

Appendix B: Ethics Review Submission

Completion of Online Research Ethics Review Submission

You have successfully submitted your application for ethics review "Application of Internet of Things (IoT) Sensors to Support Electrical Load Planning in Solar-Powered Resorts in Kenya."

Certificate awarded to: Mr Murungi, Tom

Reference number: SU-ISERC2055/24

Date and Time: 2024-02-22 19:18:31

Appendix C: Snippets of Code

Appendix C: I: Machine learning methods

Random Forest and Light-Gradient Boosting Machine (Light-GBM) comparison

```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.ensemble import RandomForestRegressor
from lightgbm import LGBMRegressor
from sklearn.metrics import mean_absolute_error, mean_squared_error, r2_score
from datetime import datetime

# Load the dataset
data = pd.read_csv('solar_data.csv')
```

```
Random Forest - MAE: 0.8070445539604005, MSE: 13.078126934517451, R²: 0.9863844108093018
LGBM - MAE: 1.10573853541597, MSE: 15.428558351448345, R²: 0.9839373854245447
```

Appendix C: II: Snippets for IoT Programming

1. Application Libraries:
   - WiFi.h: Arduino library for connecting to a WiFi network.
   - PubSubClient.h: MQTT client library for publishing and subscribing to topics.
   - Wire.h: Arduino library for I2C communication.
   - Adafruit_Sensor.h: Sensor library for Adafruit sensors.
   - DHT.h: Library for DHT temperature and humidity sensor.
   - DHT_U.h: Unified sensor library for DHT sensor.
   - BH1750.h: Library for BH1750 light sensor.
   - Adafruit_INA219.h: Library for INA219 current sensor.

```
#include <WiFi.h>
#include <PubSubClient.h>
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <DHT_U.h>
#include <BH1750.h>
#include <Adafruit_INA219.h>
```

2. Global Variables: The code defines several global variables to store sensor readings and other parameters:
   - Define DHT22 pin and type.

```
#define DHTPIN 16
#define DHTTYPE    DHT22
```

   - Instantiate objects.

```
DHT_Unified dht(DHTPIN, DHTTYPE);
BH1750 lightMeter;
WiFiClient espClient;
PubSubClient client(espClient);
Adafruit_INA219 ina219;
```

   - WiFi credentials i.e. SSID and password.

```
const char* ssid = "Enter-SSID";
const char* password = "Enter-Password";
```

- MQTT connection parameters i.e hostname, port number and MQTT subscribe topic.

```
// MQTT Broker settings
const char *mqtt_server = "broker.emqx.io";   //MQTT server.
const char *mqtt_topic = "iot/pdm ";      // MQTT topic
//const char *mqtt_username = "device1";   // MQTT username for authentication
//const char *mqtt_password = "device1";   // MQTT password for authentication
const int mqtt_port = 1883;   // MQTT port (TCP)
```

- Variables to store temperature, humidity, light intensity, and power-related values.

```
float temperature = 0.0;
float humidity = 0.0;
float lux = 0.0;
float shuntVoltage = 0.0;
float busVoltage = 0.0;
float current_mA = 0.0;
float loadVoltage = 0.0;
float power_mW = 0.0;
```

- Variables to store the last message time, a message buffer.

```
long lastMsg = 0;
char msg[50];
```

3. Wi-Fi Setup: The setup_wifi() function is responsible for connecting the ESP8266 to a Wi-Fi network. It attempts to connect to the specified SSID and password and prints the local IP address once connected.

```
void setup_wifi() {
  delay(10);
  //We start by connecting to a WiFi network
  Serial.println();
  Serial.print("Connecting to ");
  Serial.println(ssid);

  WiFi.begin(ssid, password);

  while (WiFi.status() != WL_CONNECTED)
  {
    delay(500);
    Serial.print(".");
  }

  Serial.println("");
  Serial.println("WiFi connected");
  Serial.println("IP address: ");
  Serial.println(WiFi.localIP());
}
```

4. MQTT Setup: The setup() function initializes the MQTT client (PubSubClient) and sets the MQTT server, topic, and callback function for message reception.

```
client.setServer(mqtt_server, 1883);
client.setCallback(callback);
```

```
void callback(char* topic, byte* message, unsigned int length)
{
  Serial.print("Message arrived on topic: ");
  Serial.print(topic);
  Serial.print(". Message: ");
  String messageTemp;

  for (int i = 0; i < length; i++)
  {
    Serial.print((char)message[i]);
```

5. Sensor Initialization: The setup() function initializes the DHT sensor for temperature and humidity, the BH1750 sensor for light intensity, and the INA219 sensor for power monitoring.

```
Serial.begin(9600);
dht.begin(); // Initialize device.
Wire.begin(); //Initialize the I2C bus

//begin returns a boolean that can be used to detect setup problems.
if (lightMeter.begin(BH1750::CONTINUOUS_HIGH_RES_MODE))
{
  Serial.println(F("BH1750 Advanced begin"));
}
else
{
  Serial.println(F("Error initialising BH1750"));
}

if (! ina219.begin()) {
  Serial.println("Failed to find INA219 chip");
  while (1) {
    delay(10);
  }
}

ina219.setCalibration_32V_2A(); //Calibration
```

Appendix D: Similarity Check

Masters Thesis.pdf

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