# Scenario Simulations in Microgrid Environments

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# Abstract

There have been numerous and essential advancements in the field Artificial Intelligence, Machine Learning, Internet of Things and Data Analytics. This has led to the creation of Digital Twin Technology. The Digital Twin is a virtual replica of a physical entity, that mirrors physical devices and provides constant real time monitoring and control. A Microgrid is a vital technology, which has been able to achieve large scale application of distributed energy generation. Microgrids promote the expansion and utilization of renewable energy sources and can easily overcome intermittence and randomness caused by distributed energy. But there are still numerous problems occurring within a microgrid. To solve these problems, we'll create different scenarios within a microgrid. This paper aims to discuss those problems and look for solutions. To achieve this, we'll create simulations for each microgrid scenario in a software tool and input different sets of data to look for appropriate solutions. Digital Twins equipped with Machine Learning and Artificial Intelligence decision making is supposed to build a quick learning and self-healing digital twin. Thus, this paper also discusses a few Machine Learning algorithms beneficial for the microgrids efficiency.

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# 1 Introduction

A Microgrid is a localized group of electricity sources that under normal circumstances connect to a traditional electrical grid or main grid. Microgrids are smaller versions of a centralized electricity system. They are constructed to achieve local goals of the community being served. Local goals can include reliability and carbon emission reduction.

Microgrids generate energy with the help pf Renewable Energy Sources (RES) such as Solar Energy Wind Energy and many more. Renewable energy has is very beneficial as it provides clean and non-pollutant energy but has a major shortcoming i.e. its intermittent nature. Microgrid has the ability to disconnect itself from the main grid and to operate in islanded mode and function autonomously. This comes in handy in multiple situations as it can function properly in power outages.

[13] Microgrids generate power, distribute, and regulate the flow of electricity on a local scale. Smart microgrids are a good way of integrating renewable resources at the community level and also let customers participate in the electricity business. Microgrids are one of the building blocks of the perfect power system. [15]

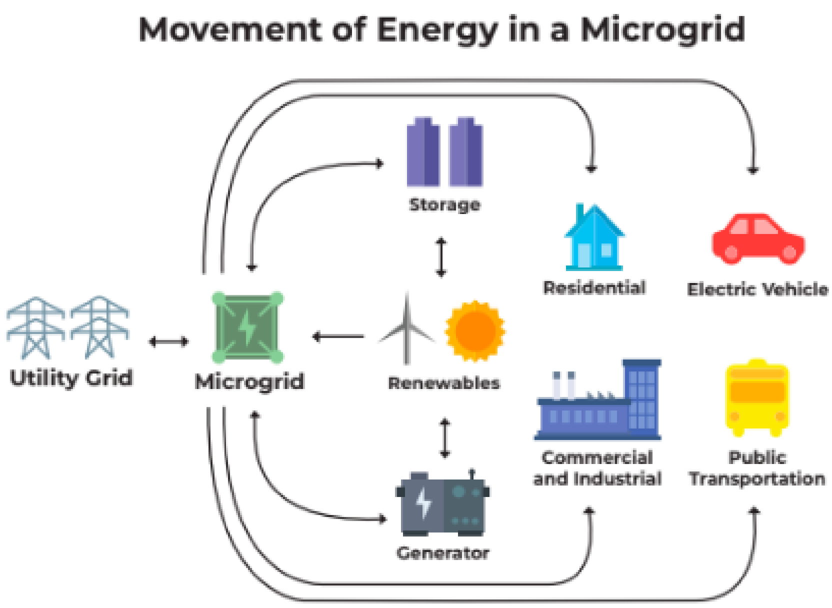


Figure 1: Microgrid Features

Figure 4 The above image depicts a Microgrid system.

## 1.1 Aim & Objectives

The aim of my research project is to discuss about Microgrids thoroughly, then discuss about different scenarios that might occur in a microgrid. Once creating the scenarios is completed, I'll run simulations for each scenario and check how the microgrid reacts on those situations. After obtaining my results from the simulations, I'll have a better understanding of what metrics are necessary for the microgrid to achieve optimal functioning.

## 1.2 Structure

Section 2 reviews the literature. Section 3 presents the research design and methodology. Section 4 describes the approach and the technical details of artefact development. Section 5 evaluates the artefacts, on the basis of research questions (RQs) in Section 5.1 and discusses the RQs in Section 6. Section 7 discusses threats to validity and Section ?? concludes the report.

# 2 Literature Review

The topic of my Project is "Scenario Simulations for Microgrids". The aim of my research project is to firstly discuss about Microgrids extensively. This includes a microgrids purpose, its popular trends and its shortcomings. The shortcomings and gaps in a microgrids design, will lead to the formation of various different scenarios occurring in a microgrid.

With the formation of these scenarios, I'll then create a virtual environment for these scenarios and then run them on a suitable microgrid simulation tool. These simulations will give us a much better insight on how a microgrid runs and how it reacts to different situations i.e. the scenarios discussed. At the end, we'll identify the necessary metrics of success in a microgrid. [4] [8]

## 2.1 Importance of a Microgrid

Microgrids are a great, reliable backup source of power in times of need. They should be considered because they cut costs and give communities access to clean energy which is environmentally friendly. They can connect to local resources which would be too small and unreliable for an entire grid system, resources like a local waterfall or unused fields which would otherwise remain unused are great resources to power a microgrid.

Power cuts annoy everyone and microgrids could be the solution to ensure an uninterrupted flow of power which would be particularly useful in hospitals and research centers. Microgrids indirectly allow for the development of undeveloped places because of the reliability of energy consumption that comes with them. [14]

## 2.2 Microgrid Shortcomings

Although microgrids offer a spectrum of advantages, its implementation and various features are still associated with multiple difficulties. They can be listed as-

- Bidirectional power flow- Microgrid includes distributed generators of low capacity, which cause power to flow in both direction which can lead to complexity in protection coordination and undesirable power flow pattern.
- Power quality issues in ac/dc microgrid
- Low Inertia- Microgrids have low inertia in order to maintain its power electronic interfaced DG's, which improve the systems dynamic performance. But when in isolated mode, the low inertia causes high rate of frequency deviations.
- Islanded mode of operation- Microgrid shifts from grid connected to islanded mode due to faults or voltage drops. In this situation, the power flow, voltage and frequency control become a major challenge for reliable and efficient operation.
- Coordinated control of Multiple DG's- Microgrid consists of multiple distributed generators and proper coordination control of these DG's is a matter of great concern.

- Energy Storage Options- The Renewable Energy Sources are very intermittent in nature and which leads difficulties in continuation of power supply. Energy storage systems not only stabilise load and generation imbalance but, also help in safe and reliable operation of microgrid.
- Economical and Reliable Operation
- Technology and Cybersecurity- Availability of low cost technology for safe, reliable operation along with need of proper control and technology for integration of renewable sources is a key challenge. [17]

## 2.3 Scenarios for Microgrid Simulations

The aim of my project is to create a virtual environment for a microgrid with the help of a Microgrid Simulation tool and then run simulations on different scenarios of a microgrid. These scenarios are-

- Temperature above a certain value i.e. a very humid day- With more energy being generated, the microgrid can store that extra energy in Energy Storage Facilities also known as Batteries.
- Rain affected or a Cloudy day- With more rain during the day, the microgrid won't be able to generate minimum required electricity for the day. In such cases, the microgrid usually uses stored energy.
- System failure- System failures usually occur in the main grid and the microgrid disconnects itself form the main grid in order to run in island mode.
- Addition of new buildings- With the addition of new buildings, more electricity will be required to run those buildings efficiently.
- More solar panels being used for energy generation- With more solar panels being used, more energy will be generated.
- More appliances requiring energy in several buildings- The energy requirements of these buildings will go up and they will require more energy to operate successfully. [3] [18]

These scenarios are further discussed in the Summary of Key Artefact Literature Section.

## 2.4 Relevant Literature Artefacts

- A. Khodaei, ”Resiliency-Oriented Microgrid Optimal Scheduling,” in IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1584-1591, July 2014, doi: 10.1109/TSG.2014.2311465.
- B. Yu, J. Guo, C. Zhou, Z. Gan, J. Yu and F. Lu, ”A Review on Microgrid Technology with Distributed Energy,” 2017 International Conference on Smart Grid and Electrical Automation (ICSGEA), 2017, pp. 143-146, doi: 10.1109/ICSGEA.2017.152.
- Sushrut Thakar, Vijay A.S., Suryanarayana Doolla,System reconfiguration in microgrids, Sustainable Energy, Grids and Networks, Volume 17, 2019, 100191, ISSN 2352-4677, doi.org/10.1016/j.segan.2019.100191.
- Shreya Dutta, Yanling Li, Aditya Venkataraman, Luis M. Costa, Tianxiang Jiang, Robert Plana, Philippe Tordjman, Fook Hoong Choo, Chek Fok Foo, Hans B. Puttgen, Load and Renewable Energy Forecasting for a Microgrid using Persistence Technique, Energy Procedia, Volume 143, 2017, Pages 617-622
- D. E. Olivares et al., ”Trends in Microgrid Control,” in IEEE Transactions on Smart Grid, vol. 5, no. 4, pp. 1905-1919, July 2014, doi: 10.1109/TSG.2013.2295514.
- Ran Wang, Ping Wang, Gaoxi Xiao, Shimin Gong, Power demand and supply management in microgrids with uncertainties of renewable energies, International Journal of Electrical Power Energy Systems, Volume 63, 2014, Pages 260-269, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2014.05.067.

## 2.5 Summary of Key Literature Artefacts

### 2.5.1 Resiliency Oriented Microgrid Optimal Scheduling

During system failures, the microgrid goes through curtailment reduction, which means that Microgrids don’t receive any energy for the main grids. This paper proposes a model that aims to minimize these curtailment loads by efficiently scheduling available resources to the microgrid when the energy supply from the main grid is halted during this system failure.

Solution- There a few uncertainties which can influence the scheduling decisions. These uncertainties cannot be controlled by the microgrid and are identified as Weather Forecast errors and main grid supply interruption. The microgrid optimal scheduling is decomposed into 2 problems, The Normal Operation Problem- this determines the optimal scheduling of dispatchable units, energy storage, adjustable loads and power transfer from the main grid. The second problem, The Resilient Operation Model- this minimises the power mismatches between microgrid generation and load.

The model comes up with an optimization method consisting of algorithms, for capturing the uncertainties. Weather forecast uncertainties can be determined by the worst-case solution of the resilient problem, which is the highest mismatch that can be resulted when uncertain parameters fluctuate. The main grid supply interruption can be captured by defining a set of islanding scenarios with different start times and duration's.

Evaluation- A mathematical modelling of the microgrid optimal scheduling problem based on resiliency considerations delivered expected benefits. Those benefits were Least cost normal operation- it determined the operations of dispatchable units, energy storage, adjustable loads and power transfer from the main grid minimises the cost of supplying local loads in normal operation.

- Resiliency Considerations- Sufficient DER's were provided for a seamless islanding.
- Uncertainty Considerations- These scenarios were determined and solved by an optimization model and worst-case analysis.
- Operational Flexibility- This model provides an efficient method for the microgrid on employing the available resources for addressing resiliency needs.

[10]

### 2.5.2 A Review on Microgrid Technology with Distributed Energy

This paper discusses the characteristics and key technologies used in a Microgrid and the key challenges existing during its development.

Solution- Microgrid has risen as an effective component for tackling the issue of energy shortage globally. A microgrid has different characteristics such as- Flexibility, it runs on grid-connected and Isolated mode. Interactivity, when operating in isolated mode, a microgrid can not only shortage the power outage, but can also help in rebooting the grid. Compatibility, Microgrid is the most effective way to achieve the connection of Distributed Energy. It integrates distributed energy and stabilises power supply. It balances between supply and demand through energy storage and controls protection, which overcomes randomness and intermittence of Distributed Energy. Economy, Microgrid has access to large amounts of Renewable energy. Microgrids can combine with medium sized heat supplies which reduce the conversion of different energy forms and improves energy efficiency.

The key technologies in a Microgrid are- Operation, when a microgrid is connected to the main grid, the microgrid provides excess power generated by Distributed Energy. When detecting failures in the main grid, the Microgrid checks the power quality and if the quality isn't up to standards, it disconnects itself from the main grid. Additionally, the isolated mode of the Microgrid provides a higher power supply reliability. Control, a microgrid provides power to its customer and can achieve this through good management and control within its system. In case there's a failure in the main grid, the microgrid disconnects itself and provides power in isolated mode. Energy Storage, the applications of energy storage plays an important role in stabilising the fluctuation of renewable energy and maintaining the systems stable operation. There are different storage technologies in a microgrid being, Mechanical, Electromagnetic and Electrochemical Energy Storage but, Batteries are the best option for renewable energy grid because of its easy instalment and manufacture. Lithium batteries and Liquid batteries are the most effective in large scale fields. Economics, its an important foundation for promotion and development of microgrid technology. The economic optimization of microgrid is different from the traditional grid as its unique design provides higher reliability.

The challenges in the development of a Microgrid are- Reliability and Stability, Microgrid is distributed in the Distribution Grid as a special power source, which can both import and export energy. The further interaction of Microgrid will affect the Distribution grids reliability. Programming and Designing, it is necessary to consider problems such as distributed power supply, microgrid structure, location and integrated optimization of distribution grid. Controlling, the distributed power supply connects the grid through an electronic inverter since there's no self-synchronization. The load fluctuation in Microgrid has a great impact on the power output. Intermittence and randomness also increase the difficulty of voltage and frequency control in distributed power supply. Protection, it is essential to ensure the safety and stability of the entire system when there's a system failure. Failure in a microgrid can occur when there's something wrong with the distribution network or when the grid operates under abnormal conditions. Scheduling, the effective scheduling and management of a microgrid can be achieved by using auxiliary tools such as modelling and simulating the microgrid to achieve protection for isolated network, overcome unfavourable factors of intermittence and randomness. [20]

### 2.5.3 Trends in Microgrid Control

This paper discusses the major issues and challenges in Microgrid grid control and reviews the state-of-the-art control strategies and trends.

Solution- There's been an increasing interest in integrating intermittent Renewable Energy Sources into microgrids reliable operation and control mechanism need to be designed. Microgrids and the integration of DER units introduces many operational challenges which need to be addressed in designing control and protection systems in order to ensure the reliability of Microgrids is not affected and the benefits of DG are fully harnessed. Some of these challenges arise from invalid assumptions typically applied to conventional distribution systems and others are resulted from stability issues observed at transmission system level.

The most relevant challenges in Microgrid Control and Reliability are- Bidirectional Power Flows, integration of DG units at low voltage levels can cause reverse power flows and lead to complications in fault current distribution and voltage control, undesirable power flow patterns. Stability Issues, local oscillations emerge from the interaction of the control systems of DG units, which further requires a thorough small-disturbance stability analysis. Low Inertia, due to the significant share of electronic-interfaced DG units, microgrids show low inertia. This can lead to severe frequency deviations in isolated operation if a proper control mechanism isn't implemented. Uncertainty, the economical and reliable operation of microgrids require a certain level of coordination among different DER's. This becomes more challenging in isolated microgrids, where the critical demand-supply balance has higher component failure rates.

The microgrids control system must ensure reliable and economical operation of the microgrid, while overcoming the above-mentioned challenges. The desirable feature a microgrid must include are- Output Control, the output voltages and currents of

DER units must track their reference values and ensure oscillations are properly damped. Power Balance, DER units in the microgrid must accommodate sudden active power imbalances, keeping frequency and voltage deviations within acceptable ranges. DSM, proper DSM mechanisms must be designed in order to incorporate the ability to control a portion of the load. Economic dispatch, DER units participating in the operation of a microgrid can significantly reduce the operating costs or increase the profit. Transition between modes of operation, this is a desirable feature of microgrids, to work in both grid-connected and stand-alone modes of operation, including a smooth transition between them. Reliability considerations must also be taken into account in the dispatch of units, especially in stand-alone operation.

The Microgrid Control Strategies can be classified into- The Primary Control, also called the local control is the first level in the control hierarchy and features the fastest response. Its control is based on exclusive local measurements and it requires no communication. The state-of-the-art techniques in Primary Control are Droop Based Methods, Non-Droop Based Methods, and the Inverter Output Control. The Secondary Control, its also known as the Energy Management System (EMS) of a microgrid. Its responsible for reliable, secure, and economical operation of microgrids in both grid-connected and isolated modes. The state-of-the-art techniques in Secondary Control are the Centralized and Decentralized Approach. The Tertiary Control, is the highest level of control and sets points depending on the requirements of the host power system. Its responsible for coordinating the operation of multiple microgrids interacting with one another in the system.

The Energy Storage System is an important technology for integrating renewable energy with microgrids. ESS can decrease losses and increase reliability. It enables large scale integration of intermittent RES. RES's are the main pillar of microgrids but without storage, their generation can't improve system reliability and has to duplicated by other means of generation. A storage unit can provide a functionality similar to the inertia of a synchronous generator by absorbing temporary mismatches between power generation and demand. [?]

### 2.5.4 Power demand and supply management in microgrids with uncertainties of renewable energies

The aim of this paper is to present an optimisation scheme to tackle the problem of fluctuating Power Demand and Supply Management in microgrids.

Solution- Power Demand and Supply Management in a microgrid are used to maintain a good match between power generation and consumption at a minimum cost. Renewable Energies constitute a significant portion of the power resources in Microgrids. But since the renewable energies are highly fluctuant, it becomes difficult for the Microgrid Central Controller (MGCC) to fulfill the customers requirement. Microgrids are expected to be more robust and cost-effective than the traditional centralized grids. They may adopt hierarchical or decentralised demand control schemes. The decentralised control scheme allows distributed energy and management of large complex systems. The hierarchical control scheme is managed by a master controller and is responsible for matching the power generation and demand load. A three-step scheme has been proposed to tackle this problem.

Firstly, to tackle the randomness nature of Renewable Energy i.e. Wind and Solar Energy, a reference distribution is introduced, and a distribution uncertainty set is defined according to past observations to confine the uncertainty. This model allows convenient handling of fluctuating renewable generation as long as the generation isn't drastically different from the past observations and empirical knowledge. Secondly, an optimization problem is formulated to determine the optimal power consumption and generation scheduling for minimizing the fuel cost. A robust approach for handling the load balance is proposed. Then the main problem is decomposed into a subproblems for an easier solution. The power demand and supply management framework discussed so far is an offline approach for planning energy consumption and generation well ahead of time. This proposed algorithm can be used in cases where the real-time adjustment is of big concern. The numerical results of the proposed algorithms indicated that the energy management scheme can significantly cut down energy expenses. Factors such as reference distribution, fault tolerant limit, types and number of uninterruptible loads and user elasticity are each carefully evaluated. These evaluations help in providing useful insights in the development of more effective policies for MGCC. [19]

# 3 Research Design & Methodology

Research designs are plans and the procedures for research that span the decisions from broad assumptions to detailed methods of data collection and analysis [5].

## 3.1 Project Deliverables

- Discuss the importance of microgrids and its popular trends.
- Answer each research question.
- Run each simulation and observe the results thoroughly.
- Discover the metrics of success for the microgrid.

## 3.2 Project Tasks

- Complete a thorough literature review of microgrid's importance, features that still require research and its popular trends.
- Find a suitable simulation software to run the different if scenarios.
- Read research papers based on the simulation software being used.
- Create different scenarios that might occur in the microgrid.
- Learn how to use the simulation software and enhance my skills.
- Search for data that will be used in the simulations.

## 3.3 Aims and Goals of the project

- Research about the gaps that are still present in a microgrid.
- Discuss about the microgrids importance and popular trends within it.
- What are the metrics of success for a microgrid and how does the microgrid achieve optimal functionality.

Research methodology is a way to systematically solve the research problem [11].

## 3.4 Essential Tools

- Node Red- I will design my microgrid environment in node red. It is a programming tool for wiring together hardware devices, API's and online services. It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its run time in a single-click.
- C Sharp Code- An essential feature of my microgrid design is its storage system i.e. the Battery. The battery must be smart enough to make its own decisions on when to store energy and on when to consume it. I will code a function for this and then run it in node red.
- OpenWeatherMap API- This tool is required for my data collection. It provides many features and is among the best in the business.
- Resource Optimization- This technique will help in evaluating the available resources with the needs of the microgrid. The management of the resources is beneficial for the microgrid. [16] [9]

## 3.5 Experiments set up

- The Microgrid Simulation tool will be set up.
- The virtual environment of the simulation will have solar panels for consuming solar energy, buildings which will consume the energy and run the whole process.
- The storage battery absorbs extra energy and provides the surplus energy when there's power shortage.
- The goal of the simulation is to achieve a fully functioning microgrid which consumes less energy and achieve carbon neutrality.

[6] [2]

## 3.6 Overview of Data Collection

Each of my simulations will require data for them to run. I will use OpenWeatherMap API to collect data. The microgrid I'm designing is located in Waurn Ponds and I will collect Waurn Ponds forecast information of 1 week. OpenWeatherMap API provides real time weather data as well as hourly weather temperature for 4 days.

# 4 Artefact Development Approach

## 4.1 Description of Artefact

My artefact consists of data I collect and the scenarios I create. For my data collection I'll be using OpenWeatherMap API to collect forecast data of 7 days of Waurn Ponds. The whole description of my data collection procedure is provided in the next section. The scenarios I'll run simulations for are provided in my literature review under, Scenarios for Microgrid Simulations. Here's a simple diagram of my microgrid and its essential features.

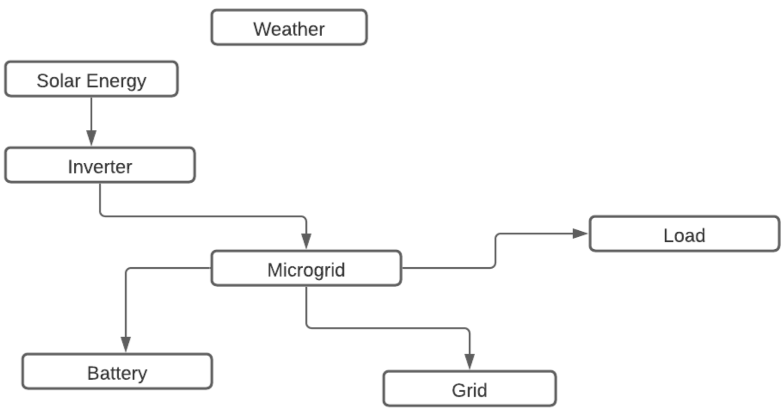


Figure 2: Microgrid Design

An essential feature of this design is the storage facility i.e. the Battery.The Microgrid powers its electricity through Solar Energy Generation. During the day the sun looms over the location and is converted into energy through the solar panels installed. There are various scenarios during the day when the solar energy generation is interrupted. The weather could either be cloudy or it might be raining. In some scenarios, there might be a small ray of light emitting during rainfall. These scenarios need to be taken in mind and must be made aware to the battery.

The solar energy generation is at its peak during noon, when the sun is at the center. The generation gradually narrows down as the progresses. Scenarios such as solar energy generation during evening must also be considered. Just to be clear, there's no solar energy generation when its dark during night time. Another specific scenario can be solar generation at early dawn.

These scenarios are very essential and the battery must be made aware of such situations. The battery must be able to make its own decisions and be aware on when to consume energy and when to store it. To achieve this, I'll be coding these scenarios on C Sharp and the results will be provided in the Results section. [7] [1]

## 4.2 Data Collection

As explained in my Research Design and Methodology, I'll be using OpenWeatherMap API to collect the forecast details of Waurn Ponds for the span of 7 days. The data will be collected on hourly basis and will be stored in a csv file. To achieve this, I followed a few YouTube tutorials which explained on how OpenWeatherMap works.

Basically, OpenWeatherMap provides each user with a unique API key, which they can use in their code to 'fetch' weather information. To achieve this, I'll create a HTML file and which declares all the important features the website will present. I will then create a JavaScript file to get my website to work. The OpenWeatherMap provides API calls, which on implementing accesses current data of any location in the world. As per my requirements, I'll collect Waurn Ponds weather of over 7 days and store it in a csv file.

# 5 Empirical Evaluation

In this section, we will discuss the evaluation plan for our artefacts, There are a total of three artefacts discussed in paper.

### 5.0.1 Scenarios for Microgrid Evaluation

The first artefact is the Scenarios for microgrids. These scenarios include unreliable weather conditions, change in supply-demand quantities and major features being affected due to communication issues, which again is caused by unreliable weather conditions. For instance, the solar energy generation takes a major hit when the whole day is affected by rainfall. This leads to no energy storage and none of the facilities get their required energy to operate. These scenarios have already been discussed in the Literature Review under "Scenarios for Microgrid Simulations".

### 5.0.2 Data Collection

As mentioned before, the data collection will be done with the help of the OpenWeatherMap API. For this firstly, we have to learn the basics on how to OpenWeatherMap. This tool works the most efficiently with the creation of a web page. This web page then displays the weather forecast of any location.

The web page can be created through a html file. The page is done with the basic style.css file. Lastly, the OpenWeatherMap API will be called on the javascript file. This is the most important part for our data collection as OpenWeatherMap collects and displays real-time data through its API and using the fetch url is important. The javascript file tag is done in the main html file.

### 5.0.3 Battery Decision Making

The last artefact is the Battery Decision Making ability. As discussed, this will be coded through C Sharp. So to begin with, the four necessary scenarios are Day, Night, Evening and Rain.

The day is when the solar energy generation takes place. It reaches its peak values at noon. The battery needs to ensure that the energy store doesn't exceed its capacity or else the microgrid system will be affected. The next scenario discussed is Night. During the night, the sky is completely dark and there's no solar energy generation. The Battery has to ensure to supply energy throughout the night. But there's a major dilemma and that is the battery might drain out all the energy it has stored.

The next scenario is Rain. During rainfall, ideally there's no solar energy generation. But in some cases, there's a small beam of light emitting from the sky and causing slight solar energy generation. Keep in mind, this solar energy generation is 1/5th of the solar energy generation during normal day light. The last scenario discussed is Evening. During Evening time, the sun sets down. It still has a portion of it left which

```csharp
using System.Security.Cryptography.X509Certificates;
using System.Collections;
using System.Collections.Generic;
using System.Timers;

public class ScenarioSimulation
{

    public enum Weather
    {
        Day,
        Night,
        Rain,
        Evening
    };

    public Weather weather;

    public int[] storedEnergyInSolarPanel;
```

Figure 3: Scenarios for the Battery's Decision Making

is emitting light for the microgrid system. This generation might be around 2/5th of the generation during normal day light. In both these cases, the battery is being stored with energy, but at a very slow rate with comparison to the generation and storage at daytime.

```csharp
public Weather weather;

public int[] storedEnergyInSolarPanel;

public bool isBatteryDrained;

public float batterycapacity, batteryEnergyConsumption;

public bool isSupplyBuilding;

public bool isSolarSupply = true;

public bool isCloudy = false, isCsvReader;

public CSVReader cSVReader;

private Timer timer1;
```

Figure 4: Variables for battery scenarios

Moving on, here's a snapshot of the important variables declared in the code. The storedEnergyInSolarPanel variable checks whether the solar panels are generating energy or not. The isBatteryDrained variable checks if the battery has drained out all the energy stored or not. The batterycapacity variable checks if the battery capacity is full or not. The batteryEnergyConsumption variable checks if the battery is consuming enough energy or not. The ifSupplyBuilding variable check whether the consumer buildings are receiving energy and the isSolarSupply variable check whether there is solar energy generation or not. This is used primarily at the beginning of the code as it allows the Battery to store energy during day time. The isCloudy variable is used during rain fall and checks if there are any clouds during the day as well. This leads to a major loss in solar energy generation. The isCsvReader variable is used for calling the csv file with the weather data. The rest of the code is explained in the Results and Discussion section. [21]

## 5.1 Research Questions (RQs)

- What is a microgrid. Discuss its importance, popular trends, shortcomings in the current state-of-the-art design.
- Define different scenarios for microgrid and run those scenarios to find metrics of success for a microgrid.

My artefact will come in use for my second research question, as the simulation will give a better insight on how a microgrid operates. The energy generated, extra energy being stored, energy being consumed by each appliance will be depicted in the simulation.

# 6 Results & Discussion

This section will discuss the results obtained throughout the trimester.

## 6.1 Scenarios for Microgrid Simulation

The most important artefact are the scenarios developed. These have already been discussed. These scenarios will be converted into a simulation on Node Red in the next phase of the project. The scenarios are as follows-

- Temperature above a certain value i.e. a very humid day- With more energy being generated, the microgrid can store that extra energy in Energy Storage Facilities also known as Batteries.

- Rain affected or a Cloudy day- With more rain during the day, the microgrid won't be able to generate minimum required electricity for the day. In such cases, the microgrid usually uses stored energy.
- System failure- System failures usually occur in the main grid and the microgrid disconnects itself form the main grid in order to run in island mode.
- Addition of new buildings- With the addition of new buildings, more electricity will be required to run those buildings efficiently.
- More solar panels being used for energy generation- With more solar panels being used, more energy will be generated.
- More appliances requiring energy in several buildings- The energy requirements of these buildings will go up and they will require more energy to operate successfully. [3] [18]

## 6.2 Data Collection

My goal for this trimester was to get my data collection procedure ready. As discussed before in the Evaluation section, I created a HTML file, designed the web page's design on style.css file and the API call was in a javascript file. The OpenWeatherMap API provides each of its user with a unique API, which is pasted in the fetch url to calculate real-time data of any location.

```javascript
var input = document.querySelector('.input_text');
var main = document.querySelector('#name');
var temp = document.querySelector('.temp');
var desc = document.querySelector('.desc');
var clouds = document.querySelector('.clouds');
var button= document.querySelector('.submit');

button.addEventListener('click', function(name){
fetch('https://api.openweathermap.org/data/2.5/weather?q='+input.value+'&appid=300840d565098e2053747f14b4833273')
.then(response => response.json())
.then(data => {
  var tempValue = data['main']['temp']-273.15;
  var nameValue = data['name'];
  var descValue = data['weather'][0]['description'];

  main.innerHTML = nameValue;
  desc.innerHTML = "Desc - "+descValue;
  temp.innerHTML = "Temp - "+tempValue.toFixed(2);
  input.value ="";
})

.catch(err => alert("Wrong city name!"));
})
```

Figure 5: JavaScript file for calling API

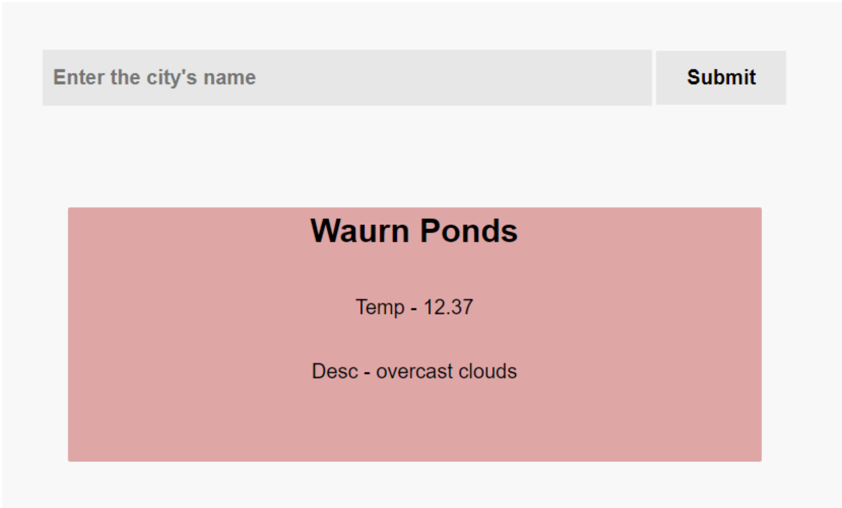


Figure 6: Web page displaying Waurn Ponds current temperature

## 6.3 Battery Decision Making

### 6.3.1 Day

The battery generation begin after a second. So the battery checks if there is any solar supply, which is true at all times during the day, the battery checks if the battery's capacity is more than its consumption. If true, the battery's charging process begins and its consumption increments. But, if the capacity is equal to the total consumption, then the battery will stop storing any extra energy. Also, the battery's capacity will never exceed its consumption. During this whole procedure, the battery keeps supplying energy to the consumer. Since, the energy is being supplied, the energy stored in the battery keeps decreasing. Once its completely empty, the battery then starts storing energy again.

### 6.3.2 Night

Its been established many a times in this paper, that there is no energy generation during night time. The battery is fully stored with energy and keeps supplying energy to the consumer buildings. There is a major threat of the battery draining out all of its energy.

```
if (weather == Weather.Day)
{

    if(isSolarSupply){
    if (batterycapacity > batteryEnergyConsumption)
    {
        Debug.Log("Battery Charge!");
        batteryEnergyConsumption++;
        //Supply To building
    }
    else if (batterycapacity == batteryEnergyConsumption)
    {
        //SolarEnergy cut no battery charge
        Debug.Log("Battery is not charging due to its full charge capacity!");
        isSupplyBuilding= true;

    }}

    if (isSupplyBuilding == true)
    {
        isSolarSupply = false;
        batteryEnergyConsumption--;
        if(batteryEnergyConsumption == 0)
        {
            isSolarSupply = true;
            isSupplyBuilding= false;
        }
    }
```

Figure 7: Code for Scenario- Day

```
else if (weather == Weather.Night)
{
    if (isSupplyBuilding == true)
    {
        if (batteryEnergyConsumption > 0)
        {
            batteryEnergyConsumption--;
        }
        else
        {
            Debug.Log("No Supply Due to battery drained!");
        }
    }
```

Figure 8: Code for Scenario- Night

#### 6.3.3 Rain

The sky is cloudy at all times when its raining. Still, there is a some solar generation occurring and its been taken in consideration. This energy is the 1/5 times of energy produced during a normal sunny day. The battery's energy storage happens at a very slow rate but eventually reaches its maximum capacity as well.

### 6.4 Evening

During the evening, the sun is at the corner of the sky. It emits solar energy but not to its full capacity. It generates around 2/5 times of the energy produced at normal day time. Again, the battery stores energy but at slow rate and eventually reaches its full capacity. On reaching its full capacity, it starts to supply energy to the consumers and starts to fill up the energy again once, battery is drained out.

```
}
lse if(weather == Weather.Rain)

  if(isCloudy)
  {
      if(isSolarSupply){
      Debug.Log("20 percent energy given to battery");//batteryEnergyConsumption 100percent
      //100 //60
      if (batterycapacity > batteryEnergyConsumption)
      {
          Debug.Log("Battery Charge!");
          batteryEnergyConsumption =batteryEnergyConsumption- 0.8f;
          batteryEnergyConsumption++;
          //Supply To building

      }
      else if (batterycapacity <= batteryEnergyConsumption)
      {
          //SolarEnergy cut no battery charge
          Debug.Log("Battery is not charging due to its full charge capacity!");
          isSupplyBuilding = true;
      }
```

Figure 9: Code for Scenario- Rain

```
else if(weather == Weather.Evening)
{
      if (batterycapacity > batteryEnergyConsumption)
        {
            Debug.Log("Battery Charge!");
            batteryEnergyConsumption =batteryEnergyConsumption- 0.4f;
            batteryEnergyConsumption++;
            //Supply To building

        }
        else if (batterycapacity <= batteryEnergyConsumption)
        {
            //SolarEnergy cut no battery charge
            Debug.Log("Battery is not charging due to its full charge capacity!");
            isSupplyBuilding = true;
        }

        if (isSupplyBuilding == true)
        {
            batteryEnergyConsumption--;
            if(batteryEnergyConsumption <=0.4f )
            {
                isSupplyBuilding = false;
                isSolarSupply = true;
            }
        }
    }
```

Figure 10: Code for Scenario- Evening

# 7 Threats to Validity

This project is low risk as it does not require many live services and all the tests are carried out in a controllable environment locally. There are still a few minor risks which need to be dealt with-

## 7.1 Use of excel as a database can limit development speed and amount of storage-

Online databases such as MySQL, MongoDB or Firebase FireStore are much faster than Excel sheets as they take minutes to do what Excel takes to do in an hour.

Additionally, MongoDB or MySQL allow us to visualise data with much less effort

## 7.2 Choosing the right simulation software

At the beginning, it was decided that my microgrid environment would be designed on MATLAB/Simulink. After working on it for a few weeks, it was found that most of its tools are already available as examples and they are not accesible for the users. This is where Node Red comes in handy as it enables users to stitch Web Services and hardware by replacing common low-level coding tasks and can be achieved by a visual drag-drop interface.

# 8 Conclusion & Future Work

his paper has discussed about Microgrids extensively. Its working, importance, features and shortcomings have been explained in detail. This paper has mentioned and even summarised various literature papers, which acted as a base and helped in completing this paper. This paper has outlined the whole research design and methodology. The artefact's approach and evaluation results have been explained in detail as well.

As per the artefacts, the scenarios have been developed after going through plenty of research papers. The Data collection was completed with the help of OpenWeatherMap API, which helped in collecting real-time weather data. he code for battery decision-making was done as well. After a lot of consideration and discussion, Node Red was chosen for simulating the scenarios and will be the focus for the next phase of the project.

## 8.1 Future Work

The aim of my project is to discuss about different scenarios occurring in a microgrid. Most of these scenarios are related to a concern that may arise within a microgrid and halt the progress. A simulation is created for each scenario, and running them is very beneficial as it solves real-world problems safely and efficiently. It provides an important method of analysis which is easily verified, communicated, and understood.

Across industries and disciplines, simulation modeling provides valuable solutions by giving clear insights into complex systems. There are still aspects of a microgrid which need to be investigated and can also be observed by modeling simulations for those components.

More research is needed on relevant technologies to highlight the best applicable communication system for microgrids, targeting overall microgrid operations, including transient response of its distributed resources. Improving reliability and minimizing delay when it comes to sensitive data transmission, such as protective relays, switches, and fault detectors is required. Machine Learning is a vast topic. It has its various advantages which can be used in optimising microgrids to their highest potential. the scenarios discussed in the paper can potentially be solved with Machine Learning and AI methods and require more research in it. [4] [12]

Moving on towards trimester 2, our focus will shift to complete each artefact. The scenarios are completed and the next step is to create microgrid environments on Node Red. The data collection is still under progress. The majority of the process id done by coding the web page and collecting current weather temperature. The next step would be to get the whole week's weather data and store it in a csv file and use it for the simulation. Lastly, the code for the battery's decision making still requires more functions. I will try to implement a few more variables in the scenarios to ensure that nothing is left out and the battery can react to any rare situation and deal with it an ideal manner.

# References


[1] M. A. Al-Shehri, Y. Guo, and G. Lei, A systematic review of reliability studies of grid-connected renewable energy microgrids, in 2020 International Conference on Electrical, Communication, and Computer Engineering (ICECCE), 2020, pp. 1–6.

[2] S. Aslam, H. Herodotou, N. Ayub, and S. M. Mohsin, Deep learning based techniques to enhance the performance of microgrids: A review, in 2019 International Conference on Frontiers of Information Technology (FIT), 2019, pp. 116–1165.

[3] A. Bani-Ahmed, M. Rashidi, and A. Nasiri, Coordinated failure response and recovery in a decentralized microgrid architecture, in 2017 IEEE Energy Conversion Congress and Exposition (ECCE), 2017, pp. 4821–4825.

[4] A. Bani-Ahmed, L. Weber, A. Nasiri, and H. Hosseini, Microgrid communications: State of the art and future trends, in 2014 International Conference on Renewable Energy Research and Application (ICRERA), 2014, pp. 780–785.

[5] J. W. Creswell, A concise introduction to mixed methods research, SAGE publications, 2014.

[6] M. R. Dadash Zadeh, A. Mazloomzadeh, H. Ghaffarzadeh, and H. Castro, Model-driven microgrid controller, in 2019 FISE-IEEE/CIGRE Conference - Living the energy Transition (FISE/CIGRE), 2019, pp. 1–6.

[7] W. Danilczyk, Y. Sun, and H. He, Angel: An intelligent digital twin framework for microgrid security, in 2019 North American Power Symposium (NAPS), 2019, pp. 1–6.

[8] P. Jain, J. Poon, J. P. Singh, C. Spanos, S. R. Sanders, and S. K. Panda, A digital twin approach for fault diagnosis in distributed photovoltaic systems, IEEE Transactions on Power Electronics, 35 (2020), pp. 940–956.

[9] K. Josifovska, E. Yigitbas, and G. Engels, Reference framework for digital twins within cyber-physical systems, in 2019 IEEE/ACM 5th International Workshop on Software Engineering for Smart Cyber-Physical Systems (SEsCPS), 2019, pp. 25–31.

[10] A. Khodaei, Resiliency-oriented microgrid optimal scheduling, IEEE Transactions on Smart Grid, 5 (2014), pp. 1584–1591.

[11] C. R. Kothari, Research methodology: Methods and techniques, New Age International, 2004.

[12] A. Lagrange, M. D. Simón-Martín, A. González-Martínez, S. Bracco, and E. Rosales-Asensio, Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: An application to a hospital, International Journal of Electrical Power  Energy Systems, 119 (2020), p. 105865.

[13] D. E. Olivares, A. Mehrizi-Sani, A. H. Etemadi, C. A. Cañizares, R. Iravani, M. Kazerani, A. H. Hajimiragha, O. Gomis-Bellmunt, M. Saeedifard, R. Palma-Behnke, G. A. Jiménez-Estévez, and N. D. Hatziargyriou, Trends in microgrid control, IEEE Transactions on Smart Grid, 5 (2014), pp. 1905–1919.

[14] S. Parhizi, H. Lotfi, A. Khodaei, and S. Bahramirad, State of the art in research on microgrids: A review, IEEE Access, 3 (2015), pp. 890–925.

[15] M. D. Phung, M. De La Villefromoy, and Q. Ha, Management of solar energy in microgrids using iot-based dependable control, in 2017 20th International Conference on Electrical Machines and Systems (ICEMS), 2017, pp. 1–6.

[16] A. Pokhrel, V. Katta, and R. Colomo-Palacios, Digital twin for cybersecurity incident prediction: A multivocal literature review, New York, NY, USA, 2020, Association for Computing Machinery.

[17] P. Singh, P. Paliwal, and A. Arya, A review on challenges and techniques for secondary control of microgrid, 2019.

[18] A. J. Veronica and D. N. S. Kumar, Load frequency controller design for microgrid using internal model control approach, 2017.

[19] R. Wang, P. Wang, G. Xiao, and S. Gong, Power demand and supply management in microgrids with uncertainties of renewable energies, International Journal of Electrical Power  Energy Systems, 63 (2014), pp. 260–269.

[20] B. Yu, J. Guo, C. Zhou, Z. Gan, J. Yu, and F. Lu, A review on microgrid technology with distributed energy, in 2017 International Conference on Smart Grid and Electrical Automation (ICSGEA), 2017, pp. 143–146.

[21] D. Zhang, N. Shah, and L. Papageorgiou, Efficient energy consumption and operation management in a smart building with microgrid, Energy Conversion and Management, 74 (2013), pp. 209–222.