Microgrid Digital Twin

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Abstract

Electricity is the future energy of this world and most of the world will rely on electricity in few coming years. But producing electricity in an unsustainable manner is also a point of concern and a concern to look upon. In this thesis, we have tried to generate electricity from a sustainable source and simulated the complete system by using digital twin technique. We have discussed about the microgrid used for electricity production and how different sources can be used to produce electricity. We majorly focused on solar microgrid electricity production because of its high feasibility and availability. We discussed about the fact that why can't we have hydro electricity microgrid or a wind electricity microgrid in detail in this thesis. We have also seen that there are several ways but most popular out of them is burning of coal which again is polluting our environment. Coming to more sustainable ways of producing electricity involves hydro power and converting of solar energy into electricity. In this thesis, we aim to design a digital twin and simulate the same to check how exactly the solar-power plants produces electric energy. Our digital twin will definitely be proven as very effective way of producing electricity with the help of microgrids. We have also discussed in detail about the digital twin technology and its uses in the current problem-solving techniques. This thesis consists a very good and innovative discussion on how to solve a major crisis of electricity which the world could face in upcoming years. This research is based on facts and numbers which we got from the dataset we used to design our digital twin. Digital Twin is a digital simulation of any real world system, but the only thing which guarantees its accuracy is that it is backed up by the real world data. It is not advisable to directly construct the idea which we have without the proof of concept and these kind of simulations help us to get to know the exact performance of the system and also we can observe the results by changing the conditions in our digital twin simulation.

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Definitions of terms

Table 1: Multirow table

DC	Direct current is the unidiretional flow of electric charge
AC	Alternating current periodically reverses directions and changes it's magnitude continuously
Photovoltaic cells	An electric device to convert light energy into electricity
Ubuntu	An operating system to perform high level tasks
Wind energy	Provides mechanical power through wind turbines
Hydro energy	It is used to produce electricity from fast running water
Efficiency	The portion of energy in the form of light that can be used to convert sunlight into electricity
Irradiance	It is the sunlight which is measured in W/m^2
Area	It is the area covered by the solar panels
Dataset	A group of files or data associated with one part of study
C#	Is a coding language for expressing operations to be performed by a system or computer
Script	Is a file that include a number of lines of code to perform operation on a machine(computer)
Load	Is the consumer who will be using the energy produced

Table 2: Multirow table

Generator	Will convert DC energy into AC energy
Storage System	Will store the energy produced to be used by the consumer

Chapter. 1

Introduction

As the world is moving towards the usage of sustainable energy, it has got many concerns attached to it. In today's world we majorly depend upon fossil fuels for energy which releases carbon dioxide and other harmful gases on burning but what if we try to replace the energy source with some more sustainable, renewable and with almost zero emission. The best answer is electricity as we are seeing that industries and automobiles are getting transformed to electric powered motors. Now one more concern which comes along with the production of electricity is that how we are manufacturing the electric power. There are several ways but most popular out of them is burning of coal which again is polluting our environment. Coming to more sustainable ways of producing electricity involves hydro power and converting of solar energy into electricity. In this thesis, we aim to design a digital twin and simulate the same to check how exactly the solar-power plants produces electric energy. Our digital twin will definitely be proven as very effective way of producing electricity with the help of microgrids.

1.1 Aim & Objectives

In this thesis, we have used digital twin to make a tuning between the real-world data and our simulator [3]. The reason behind this is very simple as it seems very impractical if we directly apply our simulator design in real world. The simulator design needs to be backed up by real data or real functionalities to be implemented in real world. So, the

simulator which we are going to use is unity 3d on which we will be having a detailed discussion in the upcoming chapters. Because of the new advancement of data and correspondence innovation, different examinations utilizing constant data or information are presently being led. The microgrid research field is developing very fast to empower smart activities of energy which is executed through digitalization [12]. Issues are faced while performing the working of the genuine microgrid example, trouble in dynamic and framework anomalies. Utilizing the digital twin innovation, which is one of the major IT advancements helping us to modernize the simulations. It is feasible to defeat these issues by changing the microgrid setup and working calculations of virtual space differently and testing the system in physical setup. In this thesis, we proposed an energy stockpiling framework activity which works on the simulator and after observing and analyzing the results, this can be applied to the real space.

In this project, we implement a digital twin of how a solar microgrid works and how electricity is being transmitted to a community [16]. This project helped us to understand the complications involved in converting the solar energy to electric power and delivering it to end user. We simulated the complete system using the Unity 3d simulator on which we will be discussing in details in the upcoming chapters. From this thesis, we aim to build a system which makes the electricity consumption cheap and provide the world with non-polluting and cheap energy sources.

1.1.1 What is a solar microgrid system?

Solar energy cannot be directly converted into electricity and used, there are solar panels which captures the solar energy and through subsequent steps it converts solar energy into usable electric energy. A microgrid system in layman's language is collecting the solar energy for a community and converting into electricity so that a community or a society gets benefitted out of it [10]. Suppose there is a locality where many families are staying, so this will be consisting of many houses and each house will have an electricity consumption. We can have electricity from the solar power plants in these type of residential areas with the help of solar microgrids. It is just installing a central solar plant which will be converting and distributing the clean electricity to all the houses. As we discussed above the electricity from the solar panels is not in a usable form and needs to be cleaned before using. The similar concept we used as digital twin in this project to make the complete utilizations of the converted energy. This can be done by installing huge and great sun-oriented solar panels and batteries in a focal area. The center of this focal area is the place where all the innovation is put away in a separate area, frequently

under the sunlight or solar based panels themselves. When the innovation has been introduced, the sunlight based microgrid is finished by associating electrical wiring from the focal force area to close houses, organizations, and ranches. Sound recognizable of how we get power. The solitary contrast is the size of the framework and the utilization of sun or solar based panels [13]. Thus, rather than families overseeing and fixing their very own generators, they are associated with a local area wide energy supplier. With microgrid, when a family turns on their lights or runs their fridge, they draw power from the 'center point' on-request. Every month, families either pay a level use charge or a metered bill for energy that they actually utilized from the bigger, shared organization. These charges are gathered and overseen by a chosen organization of local area individuals or some public welfare society (instead of a private or public service organization) and go towards future fixes or extension of the organization. In current scenarios solar microgrids have been utilized to control homes, emergency clinics, schools, organizations, water system siphons for farming, streetlamps, and the sky is the limit from here.

1.1.2 Where can we use the solar microgrid?

The sunlight based microgrids or solar microgrids are popularly considered as a feasible and economic solution in providing electricity to villages all around the globe. These frameworks are generally proper in far off networks that can't associate with existing foundation given by the public authority or privately owned businesses. Hence, they are appropriate for networks on little islands, inside rugged locales, and in distant country regions. Because of its dependence on the sun, sun oriented microgrids or solar microgrids perform at their best in areas that experience a good amount of daylight and to areas which have less exposure to sunlight, this investment is not preferred. To manage shady climate, most frameworks likewise have capacity abilities that permit them to work through stretches of inadequate daylight. Sun oriented microgrids or solar microgrids are energizing environmentally friendly power arrangement because of their application at any scale and it is very feasible to expand their capacity can be later. A portion of our sun powered microgrid or solar microgrid frameworks are enough energy to control many families and independent ventures. Should a local area develop, the sunlight based microgrid or solar microgrid can be extended to interface more families and organizations. A solar microgrid is an energy circulation network that depends on neighborhood methods and infrastructure for delivering power. It is intended to work autonomously or in synchronization with the public organization, inside a characterized region. To empower segregated or far off regions to get their financial action and

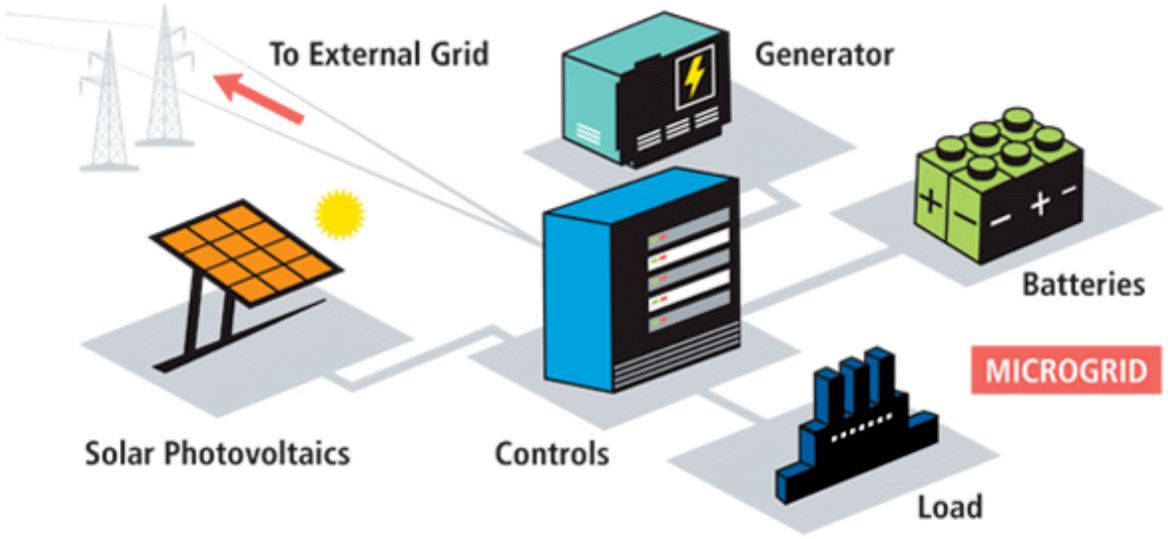

Figure 1.1: Components of microgrid

advantage from solar or sun-based energy, it is important to guarantee the creation and circulation of power. It creates a clean and sustainable form of energy which can help us to run our daily activities. Microgrids are generally adjusted to regions with lacking or insufficient electricity supply which helps them to get clean, renewable and sustainable form of energy. The combination of neighborhood environmentally friendly power creation and energy stockpiling empowers modern structure in segregated districts to restrict the different results of a potential organization blackout. They are likewise an ideal decision for far off mobile regions as it is very difficult to supply electricity by using the power grid or the conventional mechanisms. If power or electricity is supplied by using the conventional method, then the region can face to much of power fluctuations and could end up harming the electric appliances. Till the present time there are as yet 646 million USD spent on supplying the electricity to the individuals who live without utilizing the power or electricity. On account of microgrids, distant locales could be provided by these frameworks, utilizing solar based photovoltaic frameworks or some other sustainable power source which gives them the exposure to the usage of electricity. Components of microgrid

This representational microgrid comprises of a combined solar and power plant with greatest electrical power creation and right around high-temperature power stockpiling, an adsorption chiller, a few fan loops and a photovoltaic framework with top force. Advanced digital twins need to keep a predefined level of exactness as it is initiated by the real time dataset. This is the only factor which helps us to create a simulation very close to the real world. In the current case it is associated with the administration

arrangement of the virtual solar power plant. The decision of the recreation climate for making the advanced digital twin fell on Simulator. In this recreation climate a wide scope of potential frameworks can be carried out. Any product can be introduced on a virtual machine inside the protected virtual private organization of the virtual solar power plant. Planning an advanced digital twin includes recognizing the main hubs of an energy gadget and making a model of these hubs. The model conditions of the computerized digital twin should be determined inside a given timeframe. The way toward ascertaining model states is known as addressing the model. Simulator incorporate a few solutions for tackling different situations. Nonetheless, no single strategy for tackling a model applies to all sort of frameworks. Every solution epitomizes a specific way to deal with tackling a model. The reenactment of the model should be dynamic, for example the model states constantly or quickly change over the long run. Thusly it was chosen to suggest Continuous Variable kind of solution, which shifts the progression size during the utilization mathematical reconciliation to figure consistent states of a model at the current time step dependent on the states at past time steps and the state subsidiaries. The progression size characterizes the specific time-frame between progressive estimations in the state of any model. At first, the advanced digital twin was dispatched and worked persistently continuously, conveying a message to the focal framework the board each moment. Later on, the disadvantages of this strategy for activity were uncovered, like conceivable desynchronization with the continuous of the PC, just as the powerlessness to make amendments and changes to the generally running model, and so on. In this manner, it was changed into a program script that is called each moment, changes the beginning and end season of the process as indicated by the worker time, and afterward begins the reenactment. During the production of electricity, simulator ascertains all necessary transitional outcomes for a time span equivalent to one moment, which is equivalent to periodicity of information transmission of the energy to the executives and control framework of the system. This technique has made working with the model more advantageous. Since building up of the advanced digital twin began soon after every one of the gadgets which were introduced in the market so that we get the best end product. This also helps us to construct a product totally defect free and as per the customer satisfaction. This digital twin of solar microgrid model incorporates electric and warm parts with agents of a few disseminated energy assets introduced in the lab, for example, joined heat and electric power plant, photovoltaics, electrical vehicle charging station, heat stockpiling, and so forth.

1.2 Contributions

1.2.1 Literature Survey:

Reading texts and papers on solar microgrid helped us to know the importance of solar power utilization and also, we got a clear idea of its implementation. The literatures which are available gives us the brief introduction of solar panels and how electricity is produced with the conversion of solar radiations. We also got to know the equipment needs to be installed on the site of solar microgrid to produce electricity. Now there was a point where we had the idea but there was no proof of the concept and for fulfilling the same, we implemented digital twin. In digital twin we feed the digital twin system with the real data to make the simulation very close to the real world. The digital twin system needs to be very accurate and if we make any changes in the system, the significance of which should be observed in the simulations.

1.2.2 Evaluations:

We have tried to involve two types of evaluation or analysis i.e., qualitative and quantitative analysis of the complete system. We have talked to many individuals who are subject experts and also to the people who do not hold expertise in power or electricity field. We have discussed about their opinions in detail in the upcoming chapters and the results gave us a clarity on people's opinion. We also analyzed our results and outputs of the digital twin to understand the usability of solar microgrid in producing the electricity.

1.3 Thesis Structure

The remaining thesis is structured as follows:
Chapter 2 introduces the background of microgrid and digital twins. An analysis of the state-of-art in the field of digital twins microgrids. This chapter also talks about the research gaps identified.
Section 3 presents the research design and methodology while building the digital twin for microgrid simulation. This chapter includes all the discussion done on building the simulation.
Chapter 4 describes the approach and the technical details of artefact development which

clearly is the simulation we are focusing on in this thesis. This chapter consists of the abstract of the project to describe on how we can achieve the requirements discussed in Chapter 3
Chapter 5 evaluates the artefacts, on the basis of research questions (RQs) in Chapter 5.1 and discusses the RQs in Chapter 6.
Chapter 7briefly discusses internal and external threats to validity.
Chapter 8 discusses the finsings in thesis while connecting them to the research questions and concludes the report.

Chapter. 2

Literature Review

2.1 Background

The power grid has advanced into patches of difficult networks that interconnect public, local, and nearby frameworks, including in excess of 7,300 force plants, 160,000 miles of high-voltage and mid-voltage power transmission lines, and a large number of low voltage power circulation lines, all with changing conditions, age and limits, which have tangled the public network. This old-fashioned foundation is wasteful for power creation and conveyance, losing of almost about 5 percent during the transportation. The failure in circulation adds to pointless non-renewable energy source consumption that adds more harmful gases into the atmosphere [9]. Apart from this, the rise in electric power has increased so much in last few years that it becomes the need of an hour to have a technology which can help us to produce great amount of electricity in comparatively low prices. The American Society of Civil Engineers appraises the use of new technologies of the current electrical framework which will cost 673 billion dollars. Besides, numerous ecological laws support the advancement of new traditional force plants. Non-renewable energy sources utilized in ordinary power are limited and will end up in the long run. Now it is the time for renewable or some unlimited source which can help us to generate electricity.

For overcoming the issue, we have come across the brilliant idea of solar microgrid which can really be helpful in generating the electricity and deliver it to a certain community [4]. Other micro grid power sources are also there but the reason we took over the solar energy is that solar energy collection is very easy and there is no need to spend extra money on the collection of solar energy. Same is not the case with hydro power or even wind mills. Firstly, there needs to be a large investment and proper space to install a wind mill or hydro power plants. For installing a wind mill, there should be a particular region of land being empty then only you can install a windmill. Even after installing the wind mill, we need to take care of the surrounding places as there should be sufficient open land space near a wind mill. Therefore, it becomes quite impossible for institutions or individuals to install windmills at any place and generate electricity. Same is the case with hydro power plants as it cannot be used by an individual user or by any institutional user because first there should be a dam full of water and then turbine needs to be installed in the dam. Then water should be passed over the turbine and the electricity is being generated by the rotation of the turbine. But same is not case with solar energy as individual users and institutional users can install solar panels in open space and can utilize the electricity produced by the solar panels. There is not any specific safety measure to be taken care while installing the solar microgrid [7].

Solar energy involves the energy in form of radiations, heat and light. The major drawback of these solar panels can be if they didn't get proper sunlight then there are chances the electrodes present on the solar panel may get faulty but the same can be avoided by time to time and proper maintenance. These panels should be cleaned time to time to increase the efficiency of the electricity produced. The current produced by solar panel cannot be used directly as it is not considered as clean current. The current produced by the solar panel needs to be cleaned up and then it becomes suitable for domestic or commercial usage. The cleaning up of current involves many phases which we will be discussing in detail in this thesis.

Chapter. 3

Research Design & Methodology

3.1 Technical specifications

Hardware and Software used in the implementation of the digital twin of solar microgrid: The hardware which is mandatory for running this digital twin simulator is specification required for the system on which this simulation is running. The system needs to have:

- 8GB of RAM or Random-Access Memory
- At least 500GB of free storage should be there. SSD storage is preferable.
- High-resolution monitor with 1366x768 or greater
- Eight core Intel Xeon Processor
- Network Bandwidth greater than 1 GbE
- Ubuntu OS

More about Ubuntu: Ubuntu is Linux based free and open-source operating system which is gives us the best out of the box performance. Although the most widely used OS is Microsoft Windows but Ubuntu is utilized majorly by people with technical background.

It has not so user-friendly user interface but the main reason behind its utilization is that it provides very fast processing of our program. Initially we faced difficulty in installing the Unity 3D on our Ubuntu system but afterwards by following some troubleshooting steps on the internet we were able to run this. We have used a C# script to read the CSV file which consists of the dataset which we used to design the digital twin of the solar microgrid system. [8] As this OS is majorly used by the people with technical background,

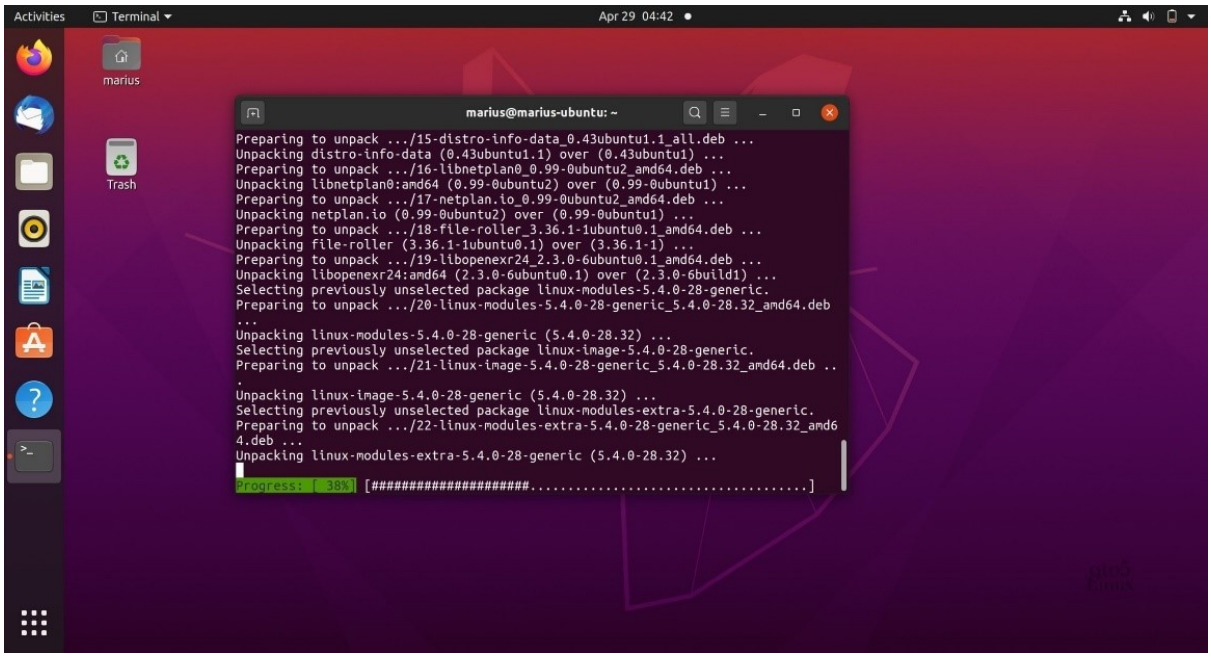

Figure 3.1: Linux Operating System

it became easy for us to run the script without any hassle. Ubuntu came in market by Cannonical which is treated as the parent company of this operating system. There are other developers too were involved when this operating system is being designed by the parent company. This company is only responsible for releasing the security updates on regular basis for the operating system ubuntu. Ubuntu name is taken from Nguni philosophy which means ubuntu is humanity to others. It seems to be correct as per the today's time as we used this IT infrastructure to develop a digital twin of such a great idea. This digital twin will definitely be proven as very useful simulation before the real-world implementation. Ubuntu also provides a great cloud support and is very favorable for running on Amazon AWS, Microsoft Azure and many more. As per the software part is concerned, we have used unity 3d to make all the visualizations and used it as a simulator in running our digital twin. Unity is considered as the game engine and was released in 2005 for Apple ecosystem by Unity Technologies. Later its support has been given to desktop, mobile, console and much more. This unity engine can be used for playing and designing games, but as far as the educational purpose is concerned, we have

unity 3d for a three-dimensional simulation. We have constructed a digital twin and for visualizing the same, we have made use of Unity 3D software. More details about this topic have been discussed in the upcoming chapters. [14]

3.2 Technologies Used

3.2.1 Micro Grid

Introduction

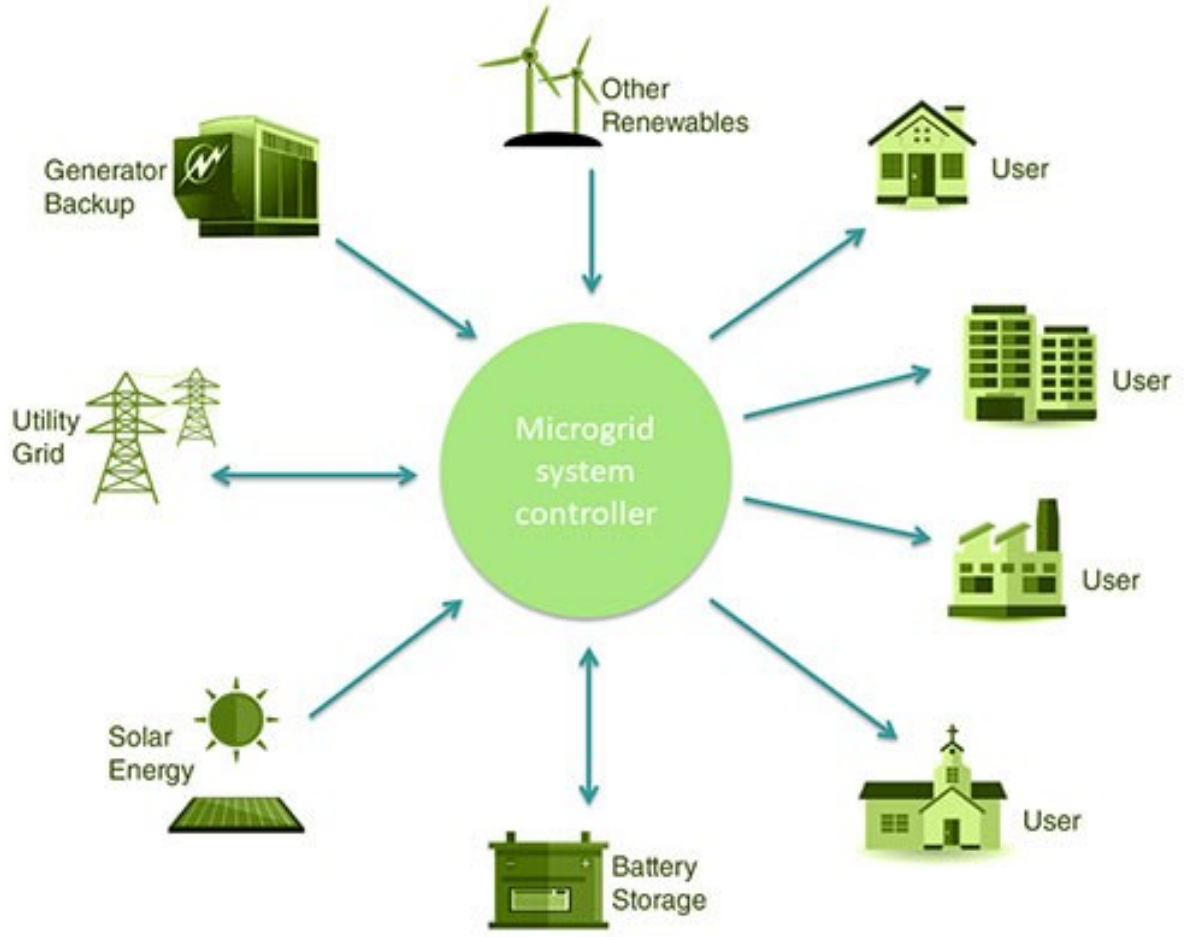

Figure 3.2: Microgrid

A microgrid is an independent energy framework that serves a discrete geographic impression, like a school and college campuses, emergency clinic complex, shopping complex, and many more. It can be defined as a limited-scale localized power station that

has its own storage capacity and generation unites and defined boundaries. The aim of using microgrids is for the distributed, decentralized, and embedded energy production. Microgrids are normally upheld by generators or inexhaustible breeze and sunlight-based energy assets and are regularly used to give reinforcement force or supplement the main supply during the high demand times. These microgrids are programmed very carefully and are connected with each other by means of some complex programming and frameworks.

Background

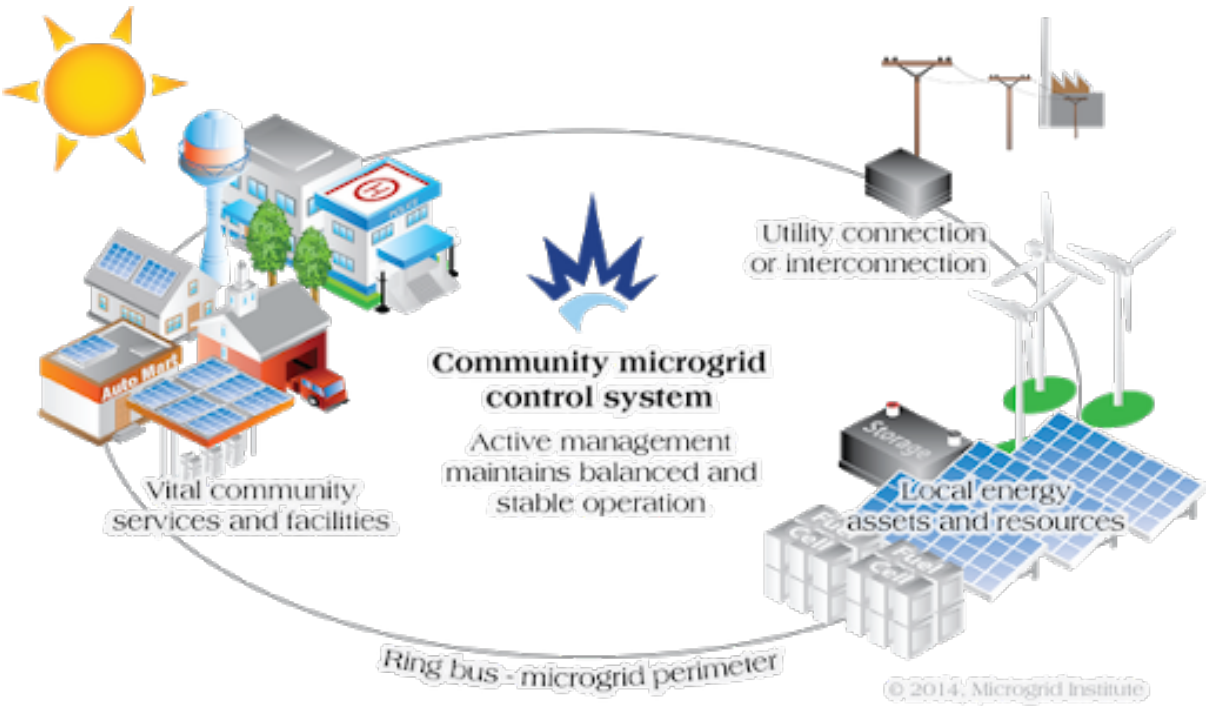

Figure 3.3: Microgrid Control System

In the same way as other innovations in the energy business, the concept of microgrid has been around in some form or other for a long time, but with some local name or name other than "microgrid", or with a similar degree of functionalities refinement and advancement that we see today. The concept of microgrid traces all the way back to the start of the electricity supply-business industry. In the year 1882, Thomas Edison opened his Pearl Street Station and there he came to know that was no norm for an age dispersion framework for power, so designed a system for the distribution of electricity using the hit and trial approach and to the great surprise that system is having the majority of all the functionalities that we have in microgrid today.

The expression "microgrid" seems to have begun being utilized in the last part of the

1990's the point at which the US Department of Energy, in line with the US Congress, started a project that works on "How to maximize the energy distribution with least costing". Later on, several researches and refinements have been done in this field and now we come up with a very refined energy distribution system "microgrid". That's not it, scientists are still working to make it more refine and advance.

How it works?

Before directly jumping to the question "How microgrid works" we need to know how the grid works. The grid makes it possible to connect homes, organizations, and different structures to focal force sources, which permit us to utilize machines, warming/cooling frameworks, and hardware. Since all of these are interconnected, so whenever any part of the grid stopped working then the whole grid is needed to be repaired.

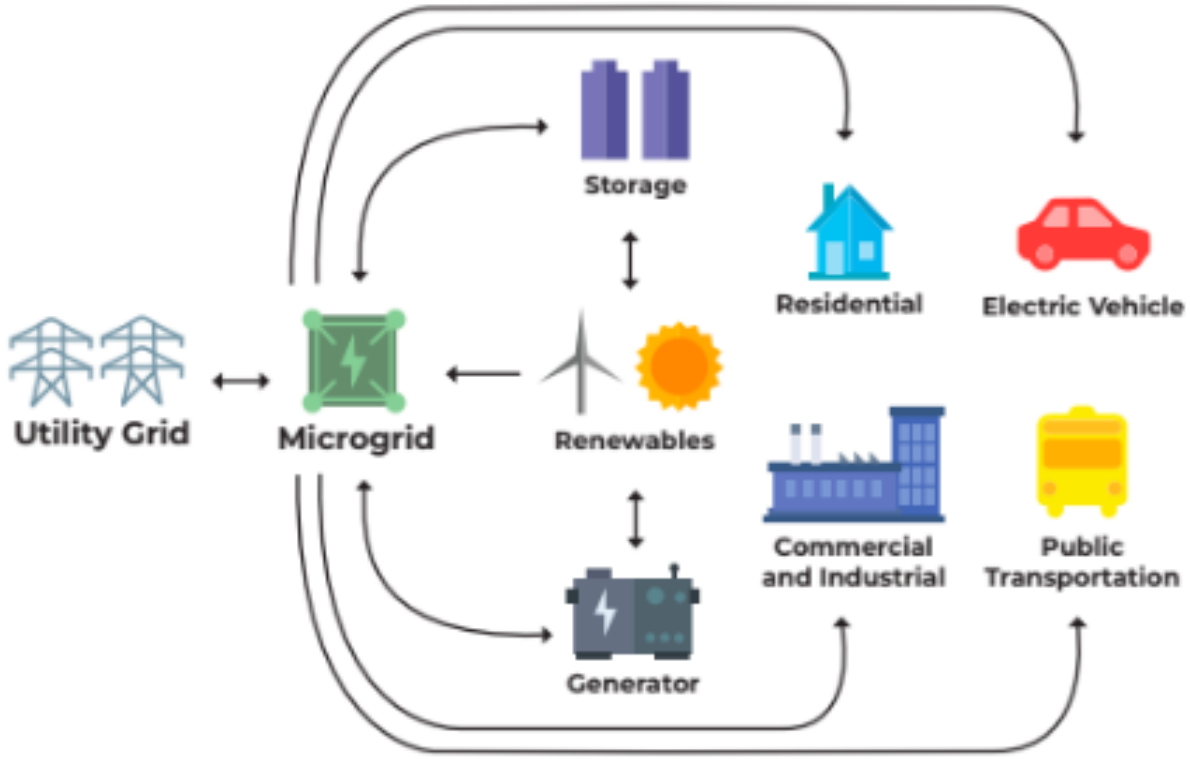

Figure 3.4: Microgrid System Working

This is the place where the concept of microgrid comes into the picture. A microgrid by and large works while associated with the network, it can operate and break off by itself by making use of local energy in case of emergencies like thunder, power outage, storms, or any natural calamity and other related issues. A microgrid can be fueled by circulated generators, batteries, and additionally inexhaustible assets like sun-

powered boards. The working of microgrid highly depends upon the question "how the requirements are managed and how the device is fuelled" In order to connect microgrid to grid, both are made to operate on same voltage level and a coupling is done between both to link them together.

Advantages –

1. The microgrid makes it possible to control and regulate the energy generated storage and power sources which can go a long way in controlling the power fluctuations in renewable sources of energy and thus improves the overall quality of the power generated.

2. Microgrids offer numerous monetary advantages. Accept sun-powered boards for instance. While they take from 7-20 years to pay for themselves, contingent upon state tax reductions or limits, they can save you a large amount every year once paid off. Sun-powered boards increase the value of your home and can be more financially stable than the energy created from petroleum products, which has not only high pricing but also a non-renewable source of energy.

3. Microgrids are additionally well known because of their dependability or reliability. Take the case when the electricity needs to cover a long distance before reaching the home or when the grid is at a long distance from the home in that case the chance of sudden occurrence of any natural calamity like storm, thunder is always a cause if concern that can affect the power supply. Privately created energy doesn't need to go far, so a microgrid can give you power in any event, when outrageous climate takes out most electrical cables. On the off chance that your microgrid has differentiated and creates energy from numerous sources, for example, sun oriented and power modules, that adds one more degree of safety.

4. Microgrids are more modest, and can subsequently be introduced more rapidly than customary power plants. It is easy to incorporate the microgrids in the remote areas even without any power supply. Thus the microgrids makes it possible to satisfy the ever increasing power supply demand of this rapidly growing population.

Disadvantages –

1. Synchronization and coupling of the microgrid and grids can be hectic and creates an issue.

2. To ensure the long, proper and efficient working of the microgrid, it is needed to be fuelled up properly and all its requirements should be managed with high priority.
3. In order to store the electricity generated we will be needing some space resources because we will be needing some energy storage devices to store them.
4. Microgrid security is a deterrent remaining against the execution of microgrids.
5. Standby charge can also be a cause of concern.

3.2.2 Digital Twin

Introduction

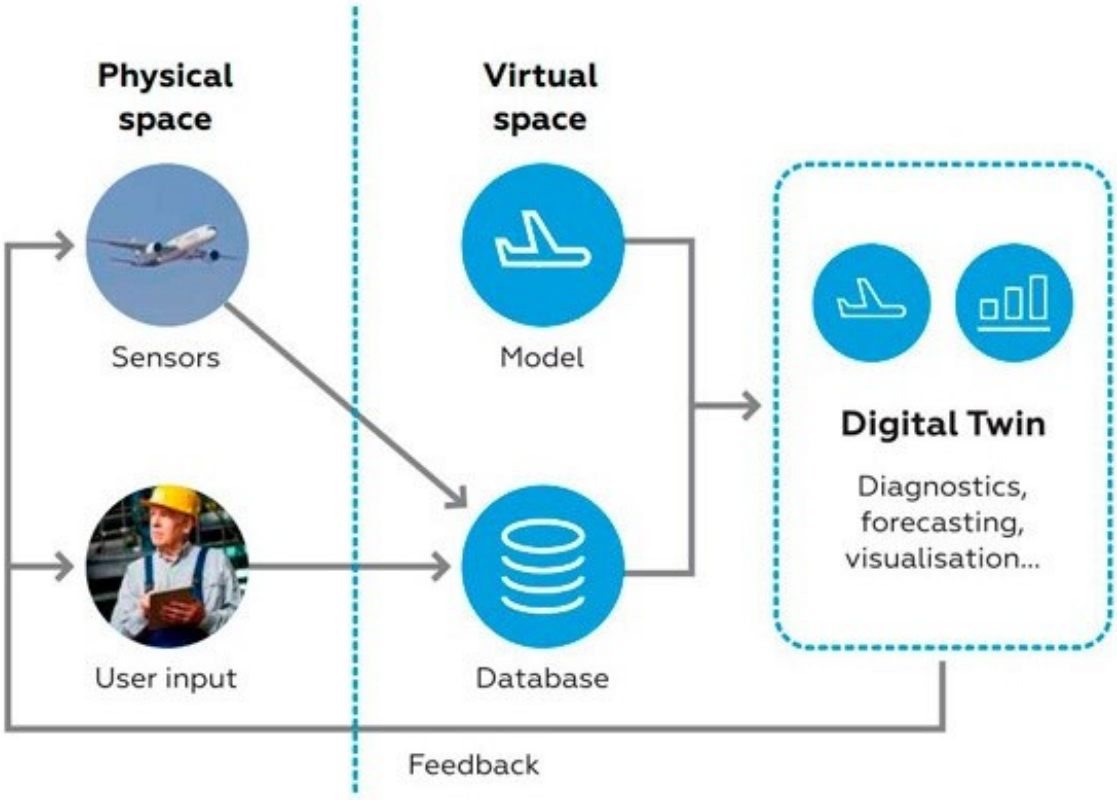

Figure 3.5: Digital Twin Example

As the name itself indicates the digital twin is a digital portrayal of any object, service or process. A digital twin can be a digital reproduction of an article in the actual world, for example, a stream motor or wind cultivates, or much bigger things like structures or

even entire urban areas.[5] As digital twin can be used to replicate the objects and services so it can go a long way in simulating the actual working of the objects which further can be used to perform operations and model training in machine learning. Digital twins are virtual imitations of actual gadgets that information researchers and IT experts can use to run recreations before directly working and operating with the actual devices. They are additionally changing how advancements like IoT, AI, and investigation are upgraded.

Background

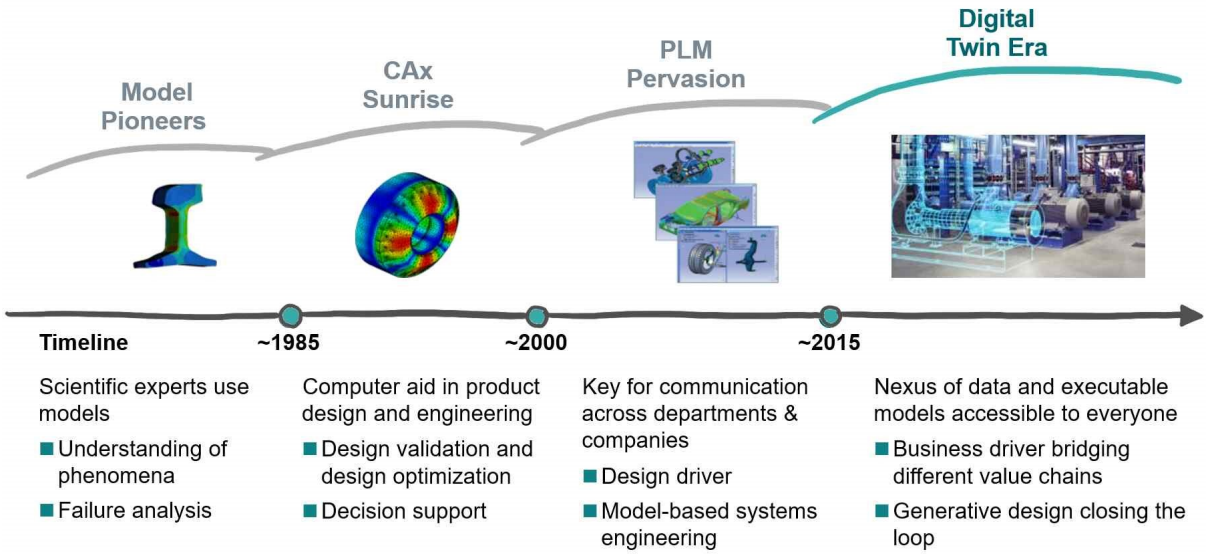

Figure 3.6: Background of Digital Twin

Despite the fact that the idea started before the main viable meaning of digital twin began from NASA trying to improve the actual model re-enactment of space apparatus in 2010.[1] Digital twins are the aftereffect of persistent improvement in the making of item plans and designing exercises. Item drawings and designing details advanced from carefully assembled drafting to PC supported drafting/PC helped configuration to demonstrate based frameworks designing. Before, actual space assumed the primary part of the business. Back then, actual resources close in distance were coordinated by people to deal with plan and assembling undertakings. In any case, because of restricted individual capacities and geological requirements, high effectiveness was difficult to accomplish. Different nations are uniting on this pattern as the following mechanical insurgency and have proposed related public procedures, like Industry 4.0, the Industrial Internet, and Made in China 2025. Until now, an expanding number of associations and organizations know of the upsides of the DT, putting a lot of assets into important examination and organization. In future, more noteworthy abilities of the DT will

be investigated and it will assume a filling part in industry for the coordination and combination between the physical and virtual spaces.

How it works?

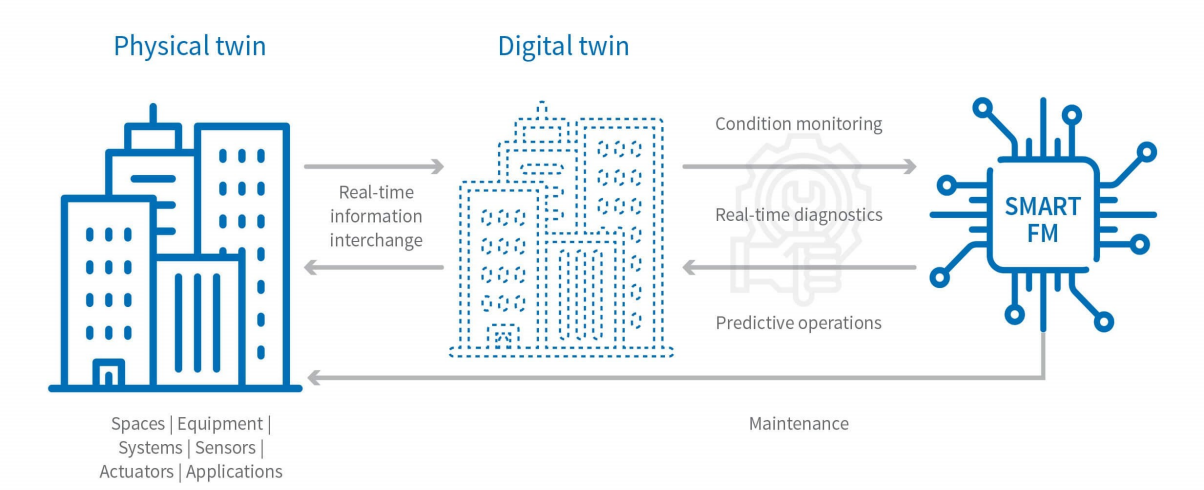

Figure 3.7: Digital Twin Working

A digital twin is, fundamentally, a PC program that utilizes real-world and real-time information to make reproductions that can anticipate how an device, service, process will perform. These projects can coordinate the IOT, computer algorithms, and human mind to improve the yield. In layman's terms, consider it as an extension between the physical and digital universes. To begin with, smarts devices and components that collets information about status, working conditions, and position of an actual device are coordinated into an digital device to make the simulation of the actual device. These parts are associated with a cloud-based framework that gets and measures all the information that the sensors screen [1]. Then the team of analysts, analyses the simulation so formed against business and other context-oriented information. Exercises are learned and openings are found inside the virtual climate that can be applied to the actual world – eventually, to change your business. A Digital Twin can likewise be depicted as a virtual model of a actual device, service or a process that can be checked, investigated, and improved. The model is made utilizing PC helped to design and is incorporated with the IOT, AI, and ML examination. It is a virtual model of a "living" and dynamic item, which will keep on updating itself whenever the actual twin goes through some changes. It is additionally fit for picking up, engrossing the information on individuals, machines, and the climate wherein it exists.

Basic expectations from digital twins are –

1. It must have an identical appearance with the actual device by taking all the minor details and points into consideration.
2. Constantly analysing and supplying data about the working, advantages, disadvantages of the actual device and which further can be used to anticipate potential issues, and recommend arrangements.
3. Acts similarly as the first item during the test.

Advantages

1. It can be used to simulate any device, process or service.
2. Data collected can be used to train any machine learning algorithm and can be made to perform desired task.
3. It can be used to constantly monitor the working and usage of the device.
4. The data it provides can go a long way in research and development, where the data is analysed and on that basis new patterns or insights are formed.
5. It reduces the maintenance cost because we can speculate any maintenance issue before it actually occurs.
6. Improved item quality and upgraded understanding into the presentation of your items in different constant applications and conditions.
7. The development in this technology results in new business opportunities.

Disadvantages

1. This technology is completely depends upon internet connectivity, so if any issue arises in the internet then that will also affect the working of the digital twin simulation.
2. Since it is internet dependent so there is also a chance of security hacks.
3. The difficulties required here incorporate globalization and new assembling methods. Dealing with all these plan information for digital twin among accomplices and providers as the actual item advances will be a test.
4. The concept of digital twin is 3D CAD model based not on 2D.

3.2.3 Unity 3D

Introduction

Figure 3.8: Unity 3D

Unity is as of now the most famous gaming motor utilized by engineers all across the planet. It has an incredible visual interface for making games, cross-stage improvement, and an effectively contributing community. Unity is a cross-stage game motor basically used to foster computer games and reproductions for PC, consoles, cell phones, and sites. It is created by Unity Technologies and was first declared distinctly for OS X, at Apple's Worldwide Developers Conference in the year 2005, it has since been reached out to pretty much every accessible stage.[11] Various efforts have been made to make it compatible with the different operating systems and platforms like mobile, console, desktop e.t.c. It is especially famous for iOS and Android portable game turn of events and utilized for games like Pokémon Go, Monument Valley, Call of Duty: Mobile, Beat Saber, and Cuphead. It is referred to be not difficult to use for fledgling designers and is mainstream for Indie game turn of events. The motor can be utilized to make 3D and 2D games or simulations, just as intuitive reenactments and different encounters. The motor has been embraced by enterprises outside video gaming, like design, design, automotive, film, and development.

Background

The Unity game motor dispatched in 2005, meaning to "democratize" game improvement by making it available to more engineers. The following year, Unity was

named sprinter up in the Best Use of Mac OS X Graphics class in Apple Inc. Apple Design Awards.[9] Unity was at first delivered for Mac OS X, later adding support for Microsoft Windows and Web programs. Unity 2.0 dispatched in 2007 with around 50 new highlights. The delivery incorporated an enhanced landscape motor for definite 3D conditions, constant powerful shadows, directional lights and spotlights, video playback, and different highlights. The delivery likewise added highlights whereby engineers could work together more without any problem. It incorporated a Networking Layer for designers to make multiplayer games dependent on the User Datagram Protocol, offering Network Address Translation, State Synchronization, and Remote Procedure Calls.

How it works?

Everything in Unity occurs in scenes. Your game's title screen will be a scene, the end credits will be a scene, your game-play will occur on a screen (or a few of them), hell, even your choices menu maybe a scene. Each scene in Unity is made with objects, similar to everything in a standard stage play. You are arranging cardboard patterns in a phase play scene, though you're masterminding things like sound sources, light sources, players, cameras, and guides in a Unity scene.

Entertainers in plays for the most part have scripts that mention to them what they should do, act, and say whenever during the play. Additionally, a few or all items in a Unity scene may have scripts that guide them, when to do it. Causing these contents to include composing code (Usually C# or JavaScript) and connecting them to the articles you need the code to influence. For instance, in the event that I have a spaceship in my scene, I would compose a piece of code for moving it around with the bolt keys. I would save that piece of code as content, and afterward, connect that content to the item that is my spaceship. (Everything in a Unity scene is, here and there or the other, an item, recollect.)

Advantages

1. One of the major advantage of unity is that it is very economical and help to simulate any product or service in a very cheap price.
2. Unity gives a very clear and excellent visual representation of the desired product which gives a proper visualization of the system and shows how different components interact.
3. Another, the most important advantage of Unity 3D is its ability to work on cross-platforms. Thus the developer don't have to work again and again for different

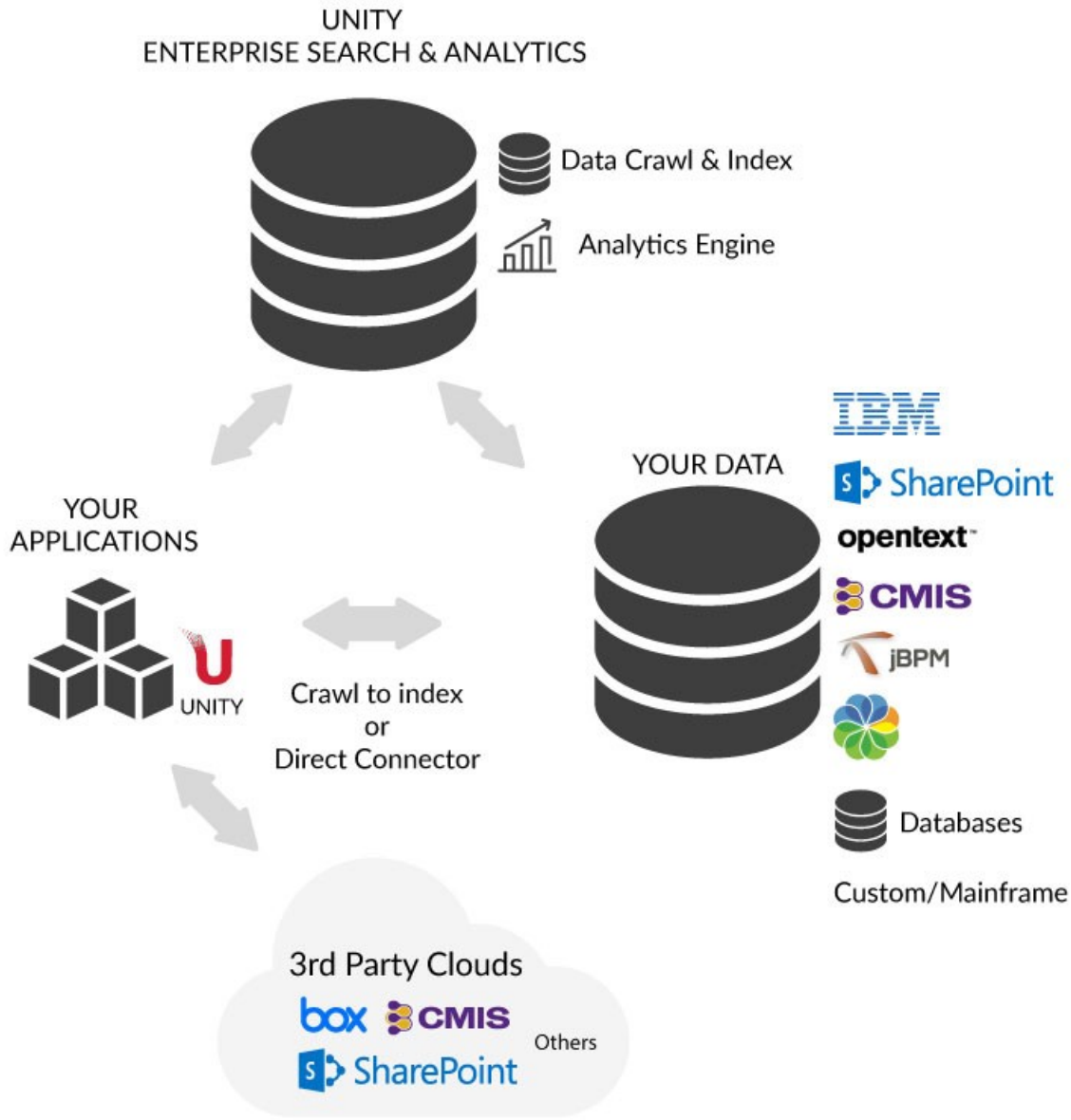

Figure 3.9: Working of Unity 3D

platforms. It follows the principle of develop once and use everywhere.

4. It is additionally simpler to utilize when compared with numerous different technologies. There are so numerous other technologies available that become harder while we use them.

5. Unity provides a well-developed and easy to use IDE (Integrated development environment) that makes easy for developers to write a complete code in multiple languages.

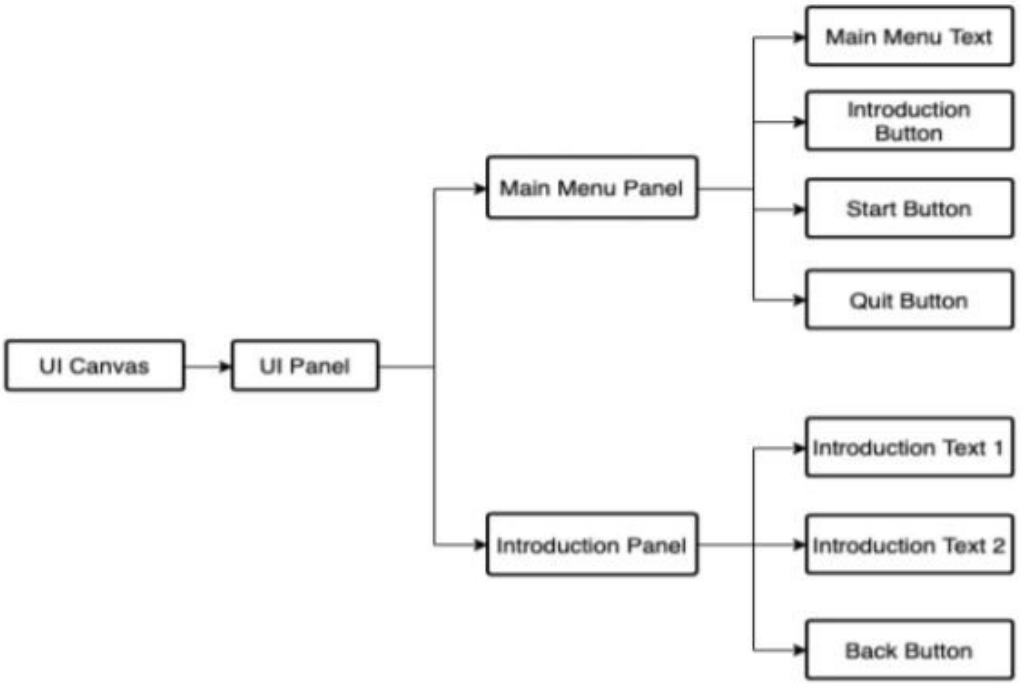

Figure 3.10: Unity 3D workflow

6. The exploring and tweaking are extraordinarily less difficult with Unity game improvement since every one of the game components is appeared during progressing association, empowering the designers to investigate the methodology at runtime.

Disadvantages

1. The code is consistent in Unity as opposed to various motors and squeezed with an unbelievable plan that improves the game application execution. Regardless, the unavailability of the source code makes finding, tending to, and fixing the show issues inconvenient.

2. The development of application in unity is very memory expensive which might results in troubleshooting problems.

3. Certain description in the official documentation about unity usage is very outdated, thus making it difficult to understand and use.

4. The unity is very bad or weak in memory management, the cache memory or garbage memory is very frequent and it is difficult to erase them completely thus the developer have to use multiple tricks to make it memory optimize.

5. The updates are very frequent in unity which is a good thing but sometimes it results in addition of new bugs in the software which might create problem for the developer and might results in the complete collapse of the developed product.

3.2.4 Droop Control

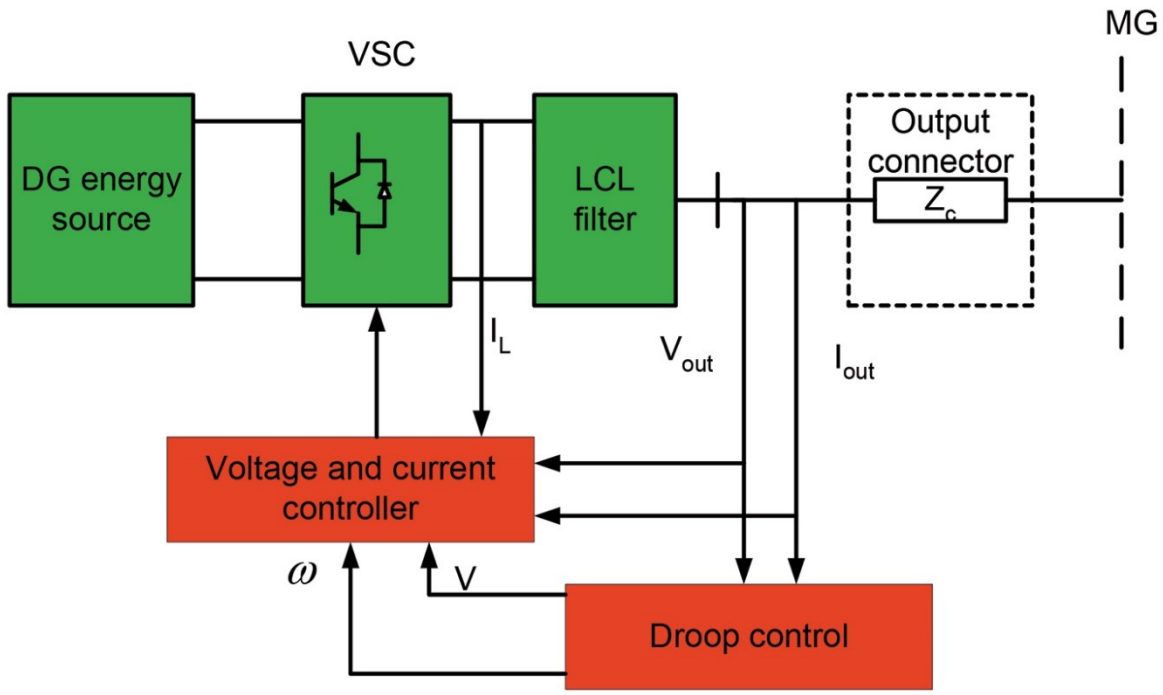

Figure 3.11: Droop Control

Droop speed control is a control mode utilized for AC electrical force generators, whereby the force yield of a generator diminishes as the line recurrence increments. It is normally utilized as the speed control method of the governor of a central mover driving a coordinated generator associated with an electrical lattice. It works by controlling the pace of force delivered by the central mover as indicated by the matrix recurrence. With droop speed control, when the network is working at the most extreme working recurrence, the main player's force is reduced to nothing, and when the matrix is at the base working recurrence, the force is set to 100This mode permits simultaneous generators to run equal so that heaps are divided between generators with a similar droop bend in relation to their force rating. Practically speaking, the droop bends that are utilized by generators on enormous electrical frameworks are not really direct or the equivalent and might be changed by administrators. This allows the proportion of force used to differ contingent upon load, so for instance, baseload generators will create a bigger extent at

low interest. Soundness requires that over the working recurrence range the force yield is a monotonically diminishing capacity of recurrence.

How droop control works?

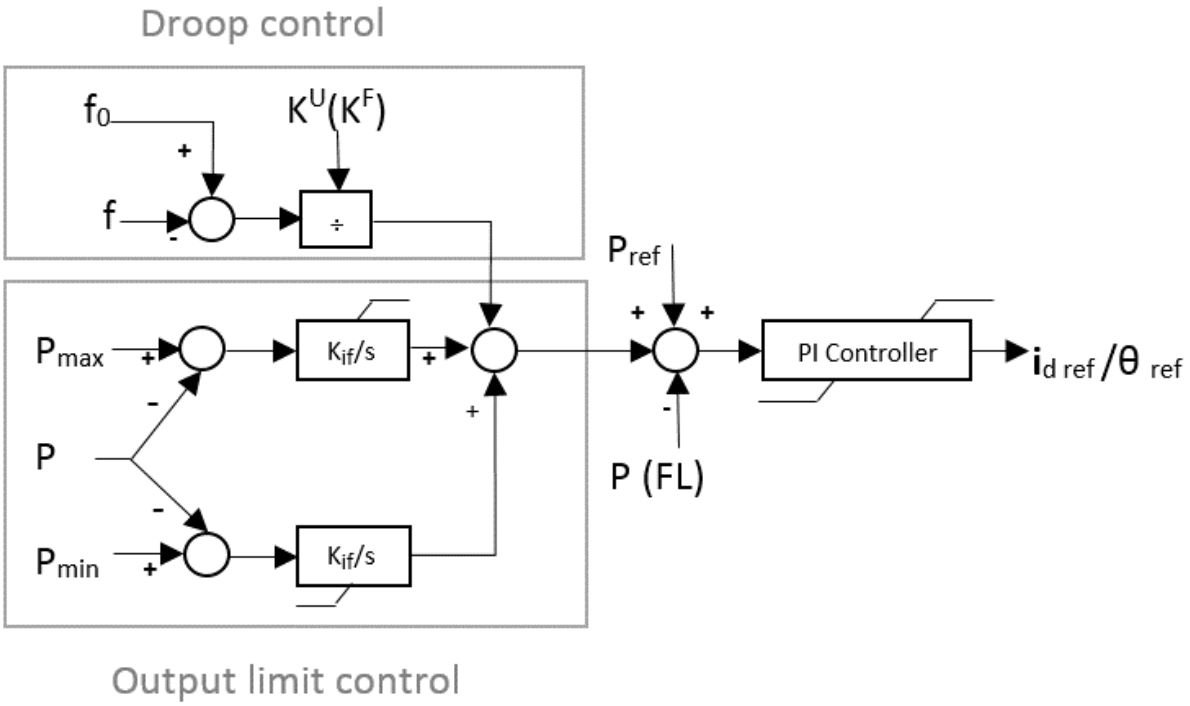

Figure 3.12: Working of Droop Control

The frequency of the synchronous generator can be calculated using the formula –

F = PN/120

Where,

F denotes Frequency

P denotes Number of poles

N denotes the speed of generator

And the Droop percentage can be calculated using the formula –

Droop percentage = (No load speed – Full load speed)/No load speed

The O/P voltage of virtual impedance can be calculated using the formula-

The park's transformation for the impedance angle can be calculated using the

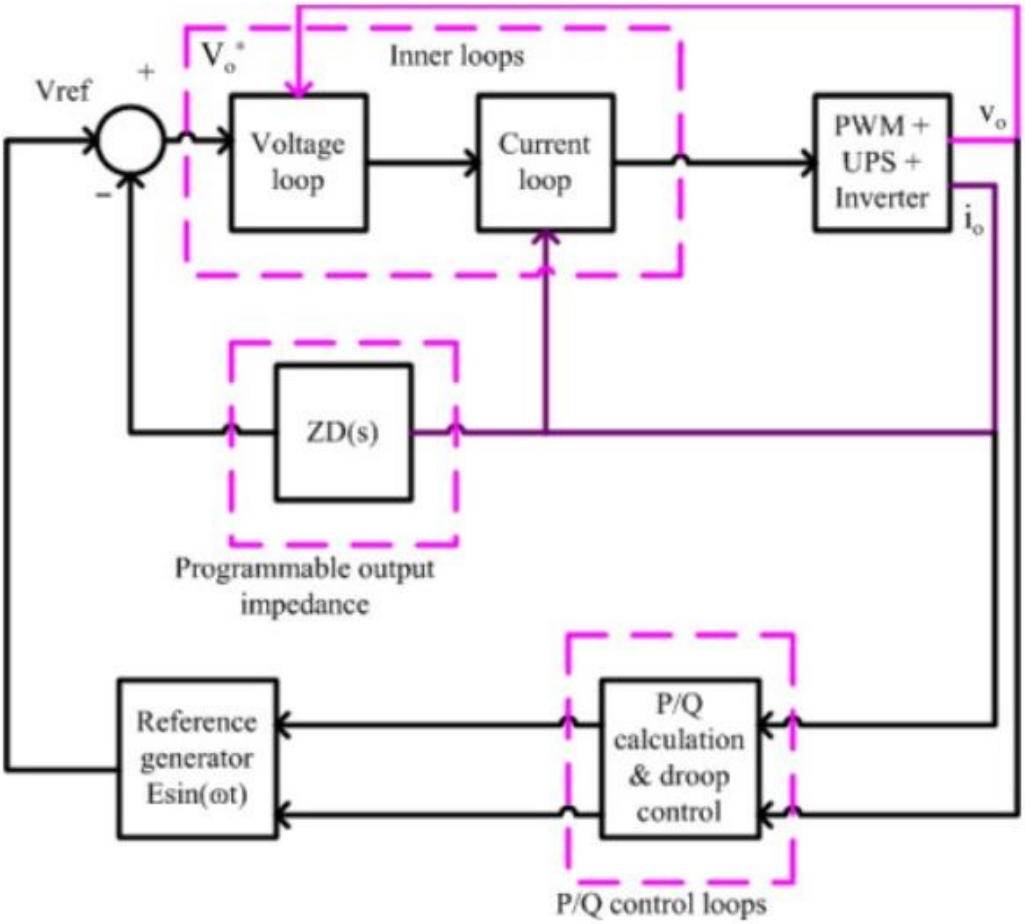

Figure 3.13: Droop Control Circuit Diagram

$$v_o{}^* = v_{ref} - Z_D(s).i_o$$

formula-

$$\omega = \omega^* - G_p(s)[(P - P^*)\sin\theta - (Q - Q^*)\cos\theta]$$

$$E = E^* - G_Q(s)[P - P^*]\cos\theta + (Q - Q^*)\sin\theta]$$

The concept of droop control is used to find out output power of the microgrid power outlet voltage and current. In order to convert the power into control signal with o/p voltage, amplitude and frequency the droop characteristic curve is used. And in order to stabalize and re-distribute the voltage, frequency and power o/p the power is reversed to the o/p voltage signal.

Advantages

1. The major advantage of droop control method is that it does not require any kind of internal interaction or correspondence between different converters in parallel type with a purpose to carry out proper sharing of power consumed by the load.
2. It is simple and easy to implement as compare to other methods.
3. Highly reliable and flexible.

Disadvantages

1. Overlooking load elements.
2. Bad transient performance.
3. Inaccurate power-sharing with O/P impedance.
4. Unacceptability for nonlinear loads.

Chapter. 4

Artefact Development Approach

4.1 System Architecture

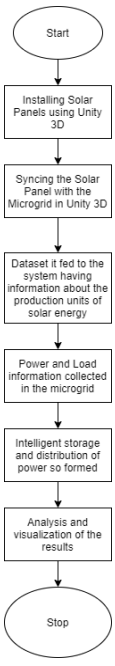

Figure 4.1: System Architecture

4.2 Methodology

As in this project, we have created a 3D simulation of electricity generation from solar energy distributed and generated with the help of microgrid.

The whole project was divided into few modules as mentioned below –

4.2.1 How to convert solar energy to electrical energy

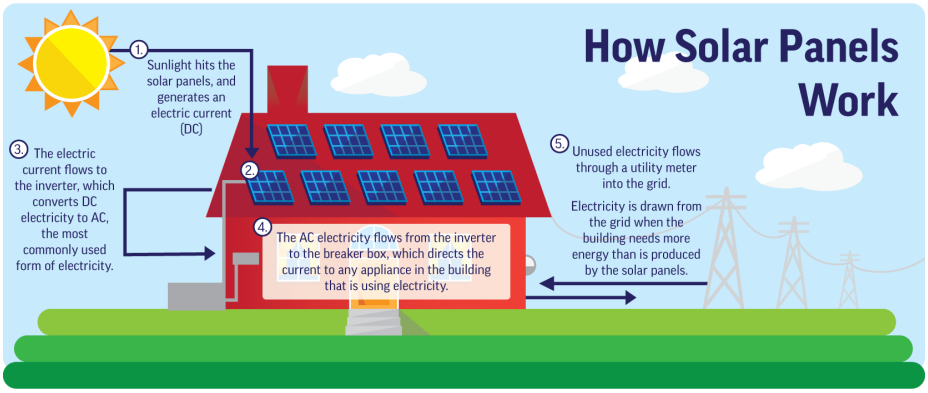

Figure 4.2: Solar Panel Working

Basics about how solar panel works

1. When the daylight falls on the solar panels and it makes an electric field.
2. The power (electric field) so formed creates streams to the edge of the panel.
3. Since the electricity so formed is DC in nature so, it is made to pass to an inverter that converts it to AC, which further is supplied to the powerhouses and buildings.
4. Another wire moves the AC power from the inverter to the electric panel on the property (breaker box), which circulates the power all through the structure depending on the situation.

4.2.2 Advantages of Solar Energy and Solar Panels

1. Among all the advantages available for the solar panels the most important one is that it is the renewable source of energy, It is available everywhere in the world

and in contrast with the other sources of energy the more we use it the better it will be for the environment. Solar energy will be open as long as we have the sun, subsequently daylight will be accessible to us for at any rate 5 billion years when as indicated by researchers the sun will pass on.

2. Solar force is a pollution-free source of energy and most importantly it does not produce any ozone-depleting substance after its production.

3. It reduces the dependence and usage of non-renewable sources of energy like fossils fuels etc.

4. The inexhaustible clean force that is accessible all year long, even during cloudy days it produces some power.

5. The solar panels require significantly less maintenance. You just need to keep them moderately perfect, so cleaning a few times each year will do the work.

6. Solar energy can be utilized for different purposes. You can create power or heat. Solar energy can be utilized to create power in regions without admittance to the energy framework, to distil water in districts with restricted clean water supplies, and to control satellites in space. Solar energy can likewise be incorporated into the materials utilized for buildings.

4.2.3 Key gaps of Solar Energy and Solar Panels

1. The solar energy is highly weather dependent, although solar energy can in any case be gathered during shady and blustery days, but the productivity of the solar framework drops by an significant amount. When Solar panels are subject to daylight they successfully accumulate good amount of solar energy. But during the cloudy, rainy day and in the night time it won't work with the proper efficiency for obvious reasons.

2. Although the maintenance cost of the solar panel is quite low but it requires a significant amount as the one time installation cost.

3. In order to generate more electricity we will be needing more solar panels and more panels means more space requirement. Thus it requires a large amount of space to generate a descent amount of electricity, so it is space expensive.

4. Despite the fact that contamination identified with solar energy frameworks is undeniably less contrasted with different wellsprings of energy, solar energy can be related to contamination. Transportation and establishment of solar frameworks have been related to the discharge of ozone-depleting substances.

Let's dive deep into the science behind the working of solar panels –

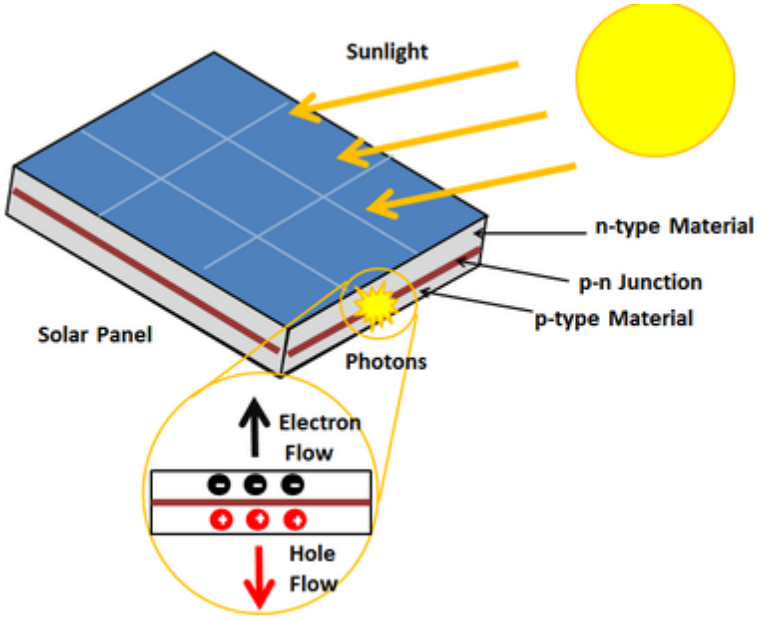

Figure 4.3: Solar Panel Photovoltaic cells

The solar panel is made up of lots of photovoltaic cells, where photovoltaic cells are the devices that convert the solar energy into electrical energy, These cells are made of semi-conductive materials, regularly silicon, a material that can lead power while keeping up the electrical unevenness expected to make an electric field. [15] Photons are rudimentary particles that convey solar radiation at a speed of 3 x 105 kms/sec. At the point when the photons strike a semiconductor material like silicon, they discharge the electrons from its particles, leaving behind an empty space. The wanderer electrons move around arbitrarily searching for another "opening" to fill.

To deliver an electric flow, be that as it may, the electrons need to stream in a similar way. This is accomplished utilizing two different types of silicon material. The silicon layer that is presented to the sun is doped with iotas of phosphorus, which has one more electron than silicon, while the other side is doped with boron particles, which have electron one less in number. The subsequent sandwich so formed works similarly to a battery: the layer that has more electrons turns into the adverse terminal (n) while the

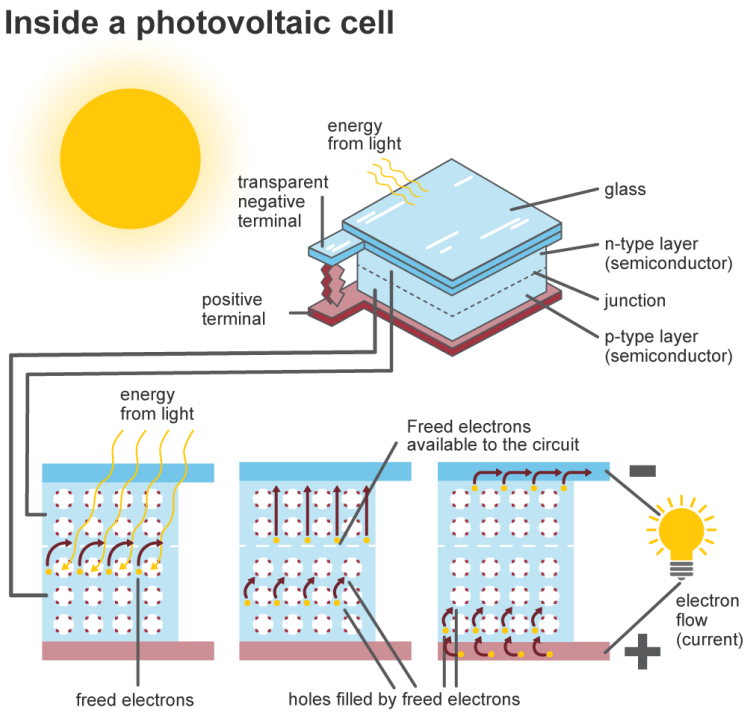

Figure 4.4: Photovoltaic cells working

side that has a shortage of electrons turns into the positive terminal (p). An electric field is made at the intersection between the two layers.

At the point when the electrons are energized by the photons, they shifted to the n-side by an electric field, while the holes to the p-side. The electrons and holes are coordinated to the electrical contacts applied to the two sides prior to streaming to the outside circuit as electrical energy. This produces direct current. And in order to reduce the loss of photon during this process, a coating is applied on the top of the surface which is anti-reflective in nature and doesn't let photos move out of the panel surface.

Since the power so formed is DC in nature and as we know our all appliances works on AC, so solar inverter is there that convert the DC into AC.

A solar inverter is a sort of electrical converter which changes over the variable DC o/p into a utility recurrence AC which further can be provided to a business electrical lattice and powerhouses. It is a basic equilibrium of framework segments in a photovoltaic framework, permitting the utilization of standard AC-controlled hardware. Solar force inverters have exceptional capacities adjusted for use with photovoltaic clusters.

Figure 4.5: Solar Inverter

4.2.4 Energy Storage and Control System in Microgird

Energy Storage System in Microgrid

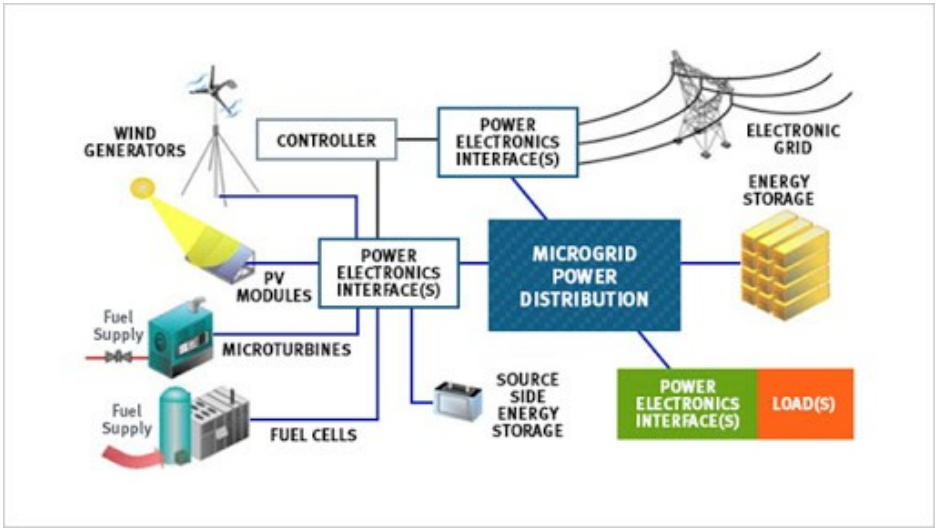

Figure 4.6: Energy Storage System in Microgrid

Energy Storage System is an innovation that stores power created from environmentally friendly power sources or from the pre-existing power grid with the aim of using it later when required. A microgrid is a discrete energy framework that gives the electric capacity to a particular area or office by coordinating with disseminated energy assets. Whenever there is an outrage in the primary grid then the microgrid directly switches into the island mode where the aim of the grid is to store more and more amount of energy in its storage resources. To store energy for sometime later, a microgrid proprietor needs an energy stockpiling framework. At the point when the principal utility can't supply power, a microgrid takes over consistently in the event that it has an energy storage system.

4.3 Energy Control and Management System in Microgrid

Figure 4.7: Energy Control and Management System in Microgrid

A microgrid is described by the appropriate integration of Storage, Consumption, and dissemination of energy resources with an aim to increase the self-sustainability of the power distribution grid's future. Such integration combination results in new difficulties to microgrid the executives that have never been presented to conventional force frameworks. So in order to solve this issue, there is the concept of intelligent microgrid management comes into the picture. The intelligent EMS takes care of few major thing like –

1. Forecasting the Energy requirements and activities

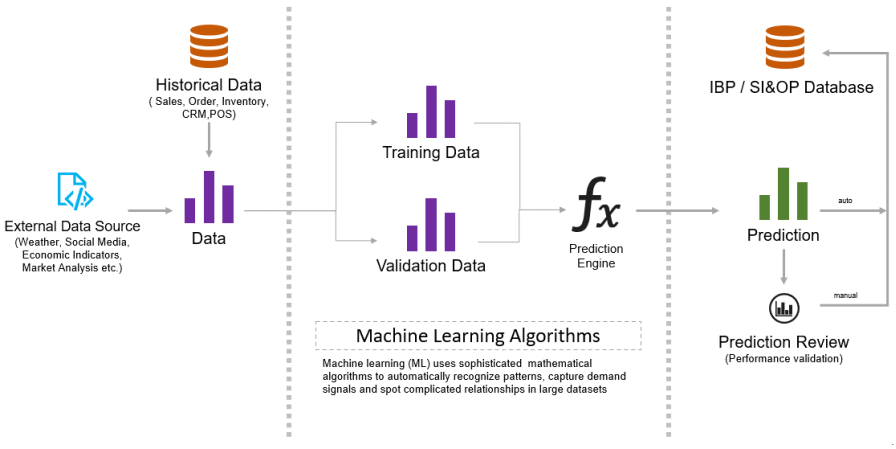

Figure 4.8: Forecasting in Microgrid

In this rapid world of advancement, the demand of energy is increasing at a very rapid speed and predicting the energy requirements and activities became the need of the hour.

So in order to forecast the activities the Intelligent management system is pre-fed with machine learning algorithms which are backed by proper data and analysis, and these algorithms are used to forecast the energy requirements and activities, and on that basis proper arrangements can be made.

2. Optimization of Energy control and activities The different areas have different energy requirements, some may have high demand and some may have low. So it is very important to have proper energy control techniques that can bifurcate the areas on the basis of the energy requirement and on that basis it further control the supply. Also it should be capable enough to activate the storage system to store the surplus energy supply and switches between different modes when required.

3. Analysis of Energy Data

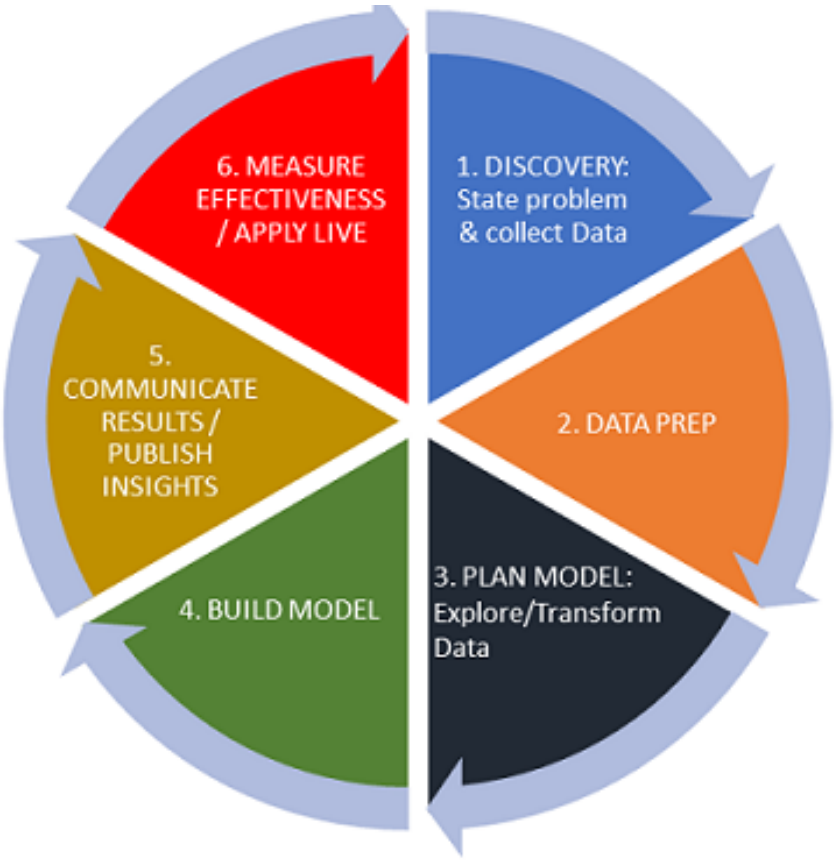

Figure 4.9: Analysis of Energy Data

Data Analysis is an another import part of the intelligent management system, The microgrid have to work all the time and it will be generating lots of data about the electrical requirement and activities of different areas, so the data so formed can be use for analytical purposes and on that basis several insights can be formed which further

can be used to derived patterns about the electrical requirements.

4. Human Machine Interface As human cannot understand the machine language and same as the case with machine, so there should be a simple and interactive user interface where the humans can interact and even a user with not much knowledge about technologies will be able to get proper insights from the system.

4.4 3D Visualization of the Modules

In order to have a better understanding about the working of different modules and to give a real-time touch to the system the concept of 3D visualization proves very helpful. There are few different modules available in the project and for them 3D visualizations are made using the unity 3D software.

4.4.1 Visualizing the solar panels

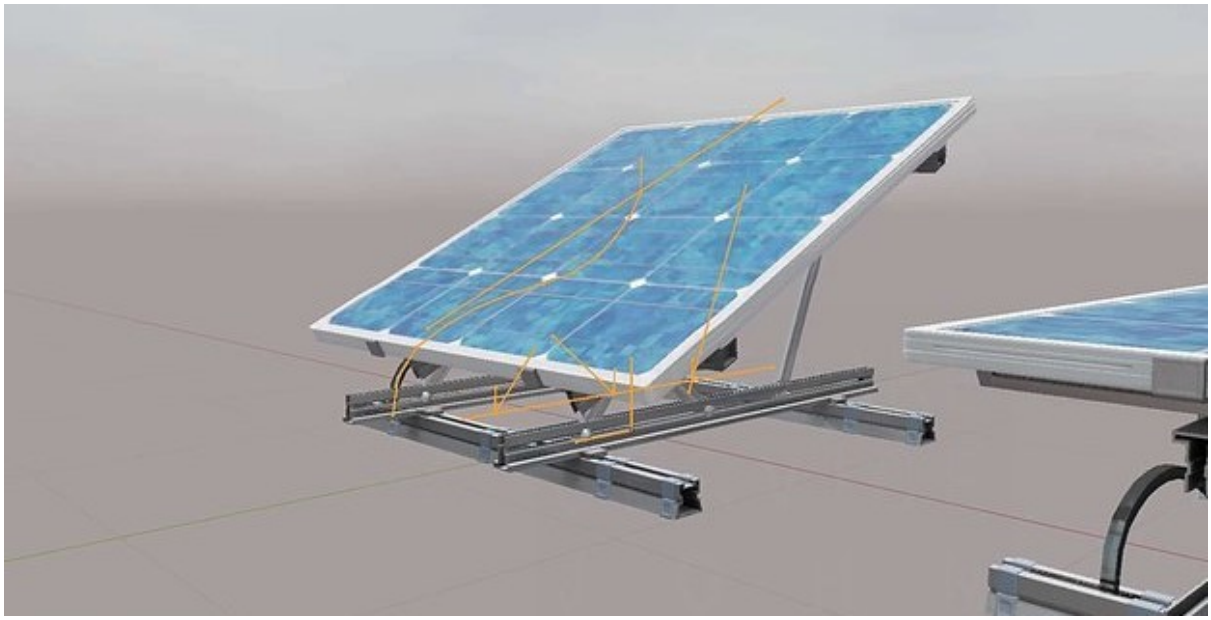

Figure 4.10: Visualization of Solar Panel

The visualization of the solar panels is made using the unity 3d software where it gives a complete information about where the solar panels are placed and at what angles the panels are installed.

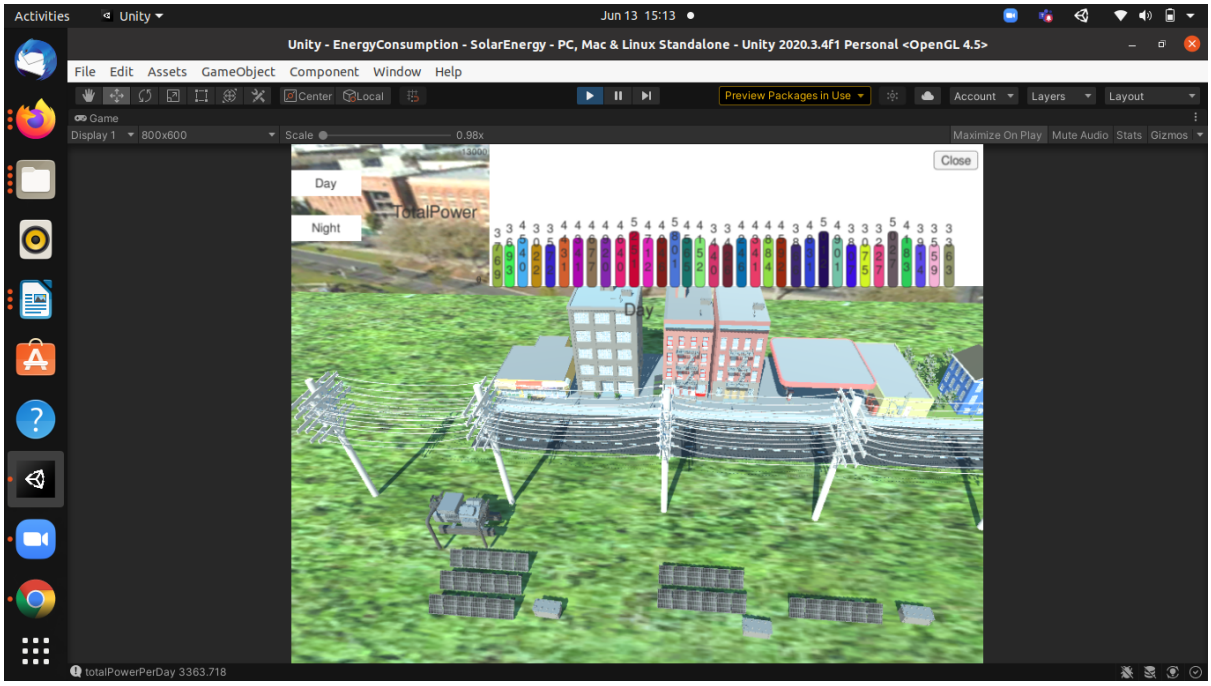

Figure 4.11: Visualization of Solar Panels and Energy Production

As shown in this image, the solar panels are install on the ground and is it different for different buildings where multi-color the bar graph in the top right corner give the units of electricity produced by the solar panel. For the building 1 there are 6 panels available, for the building 2 we have 12 panels available and for the building 3 we have 18 panels available.

4.4.2 Visualizing the Load Element

Load management is one of the main key component of a microgrid. It becomes really important to balance the load and power generation. It becomes really important for the microgrid system to evaluate the load constantly.

It becomes important to choose the right load element so that the required/necessary system flexibility to avoid the inconvenience to the load consumer.

There are different buildings(loads) available and different simulations have been made for each building(load). These kind of virtualizations give a more clear description about the real-time view of the interacting system.

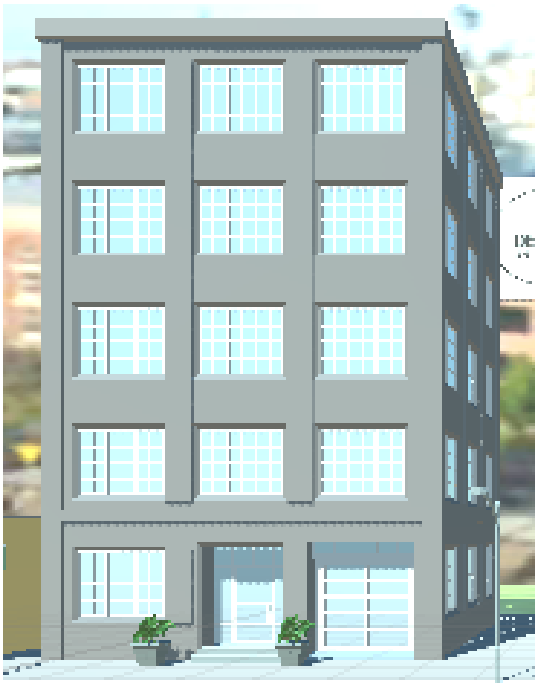

Figure 4.12: Visualization of Load Element

4.4.3 Visualizing the Energy Storage System

A battery is a power source comprising of at least one cell whose compound responses make a progression of electrons in a circuit. They by and large involve three distinct parts for example Anode, Cathode, an electrolyte that makes the current pass.

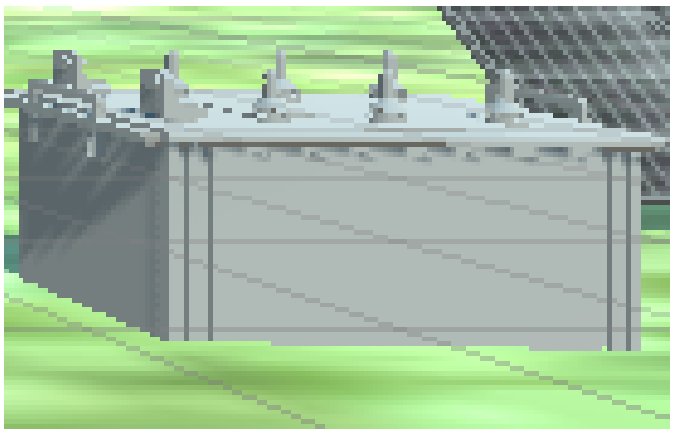

Figure 4.13: Visualization of Energy Storage System

At the point when a battery is providing electric force, its positive terminal is the cathode and its adverse terminal is the anode. The terminal checked negative is the wellspring of electrons that will course through an outer electric circuit to the positive

terminal. At the point when a battery is associated with an outer electric burden, a redox reaction took place that converts the high-energy reactants to low-energy products, and the free-energy contrast is delivered to the outside circuit as electrical energy.

4.4.4 Visualization of the Generator

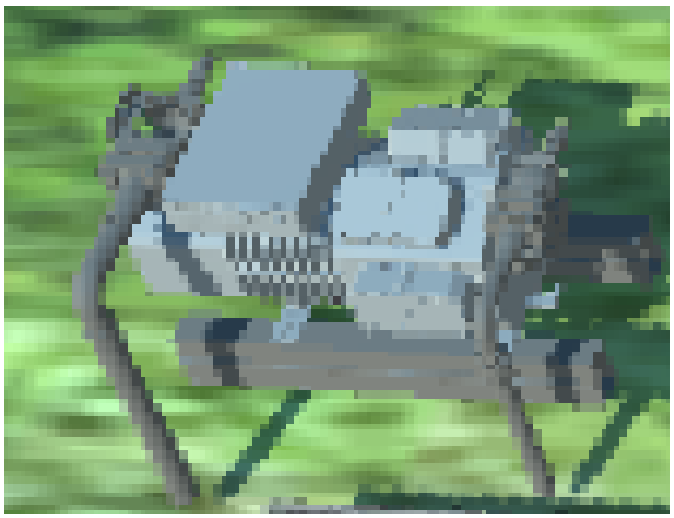

Figure 4.14: Visualization of Generator

An electric generator is a machine that converts the mechanical energy over to electrical energy which further is transmitted and dispersed over electrical cables to business, homegrown, and modern clients. The mechanical power required to generate the electricity is normally acquired from a pivoting shaft and is equivalent to the shaft force increased by the rotational, or rakish, speed. The electric generator's mechanical energy is normally given by gas, wind, steam turbines. Electrical generators give virtually all the force that is needed for electric force networks. When the generator is in operation, it creates up to 24000Volts of current. the power that is generated is a type of alternating current, which is charged to the voltage required and changed to coordinate current communicated over transmission lines as direct current, and afterward modified back to AC at the place where it is supposed to be used.

4.5 Microgrid Components

A microgrid consists of different components and each component has it's own importance, as shown in the Fig 4.15. All the elements in a mmicrogrid are necessary to

build and effective system i.e. a microgrid is not complete without an efficient storage system, photovoltaic cells, generator and the main grid.

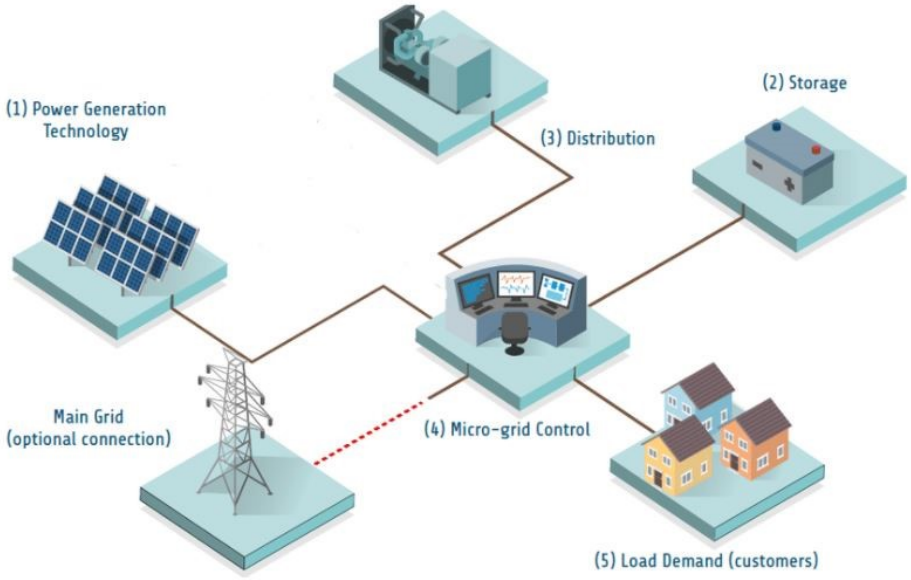

Figure 4.15: Components of Microgrid

4.5.1 Load Demand

The major segments of the microgrid comprise load management and load control. It is always required to keep an equilibrium between power demand and supply. Microgrid control frameworks need to continually check the requirement and load and take required actions to balance it. The load requirement can be different for single or multiple clients or devices as per their requirements.

4.5.2 Substation Elements in Unity 3D

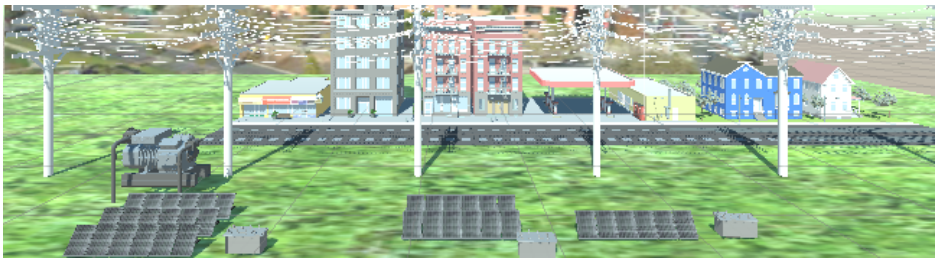

Figure 4.16: Substation

A substation plays a major role as a vital hub in the power system organization and a junction for power trade. It is the framework liable for transmission and dissemination between transmission frameworks and power generations. Substations get voltage from the force plants by high-voltage lines. Voltages are changed in accordance with necessities and dispersed to clients.

There are many different equipment involved in a substation system, which mainly could be divided into 2 types i.e. Primary equipment and secondary equipment.

Primary equipment refers to those equipment which are used in the main system of power generation and distribution etc. Some of the the primary equipment are generators, transformers, main power cables etc.

Whereas secondary equipment refers to those equipment which are required to monitor, Control and regulate the primary equipment. Secondary equipment mainly includes measuring instruments, relays, automatic devices etc. In this thesis we have only used the required primary equipment to demonstrate the working of an actual system.

Chapter. 5

Empirical Evaluation

5.1 Research questions

The research that we presented in this work aims to the following research questions. These research questions are derived from the current issues and gaps found, so we are going to answer these research questions through the formal research methods in this work.

1. How to build an effective digital twin for microgrid?
2. How to evaluate the digital twin for microgeid?

5.2 Analysis

There are majorly two types of evaluation of any system namely qualitative and quantitative Both of the evaluations we will be going to cover in detail in this chapter.

5.2.1 Qualitative Analysis:

In this analysis, we will be observing the more on the quality part of our digital twin model. In a random survey and feedbacks from the subject experts, it has been observed that electricity is something which is the need of the hour and there should be some sustainable source from which we get electricity [2]. As we talk about sustainable energy source, we get opinions of having electricity from the windmill, hydroelectricity and solar electricity but when we talk about the more feasible and most economic electricity production then the best comes out to be solar energy. After getting this idea, we thought of having a simulation or proof of concept kind of thing but then we came to know that what else can be better than the digital twin of solar microgrid. Now as we researched further, we found results on digital twin to be implemented in many areas and there are many interests for solar microgrid as well, but there has been no significant try to merge both of these concepts. In this thesis, we merged both the things i.e., solar energy from the microgrid and the digital twin. We have tried to implement the digital twin of the solar microgrid which will help us to analyze that the assumed system of installing a solar microgrid in the campus of Deakin is considerable or not [6]. The results turned out to be great and the same is discussed in the quantitative analysis of the digital twin of solar microgrid. We have also prepared a set of questions about the need of solar microgrid and collected the review of people who holds an expert knowledge in energy subject and also on the people who have no knowledge about solar microgrid, the results seem to be interesting.

5.2.2 Quantitative Analysis:

In this analysis we look at the results given by our digital twin of solar microgrid. We have installed the solar panels on the top of three building and according to our observation, building 3 is the greatest producer of the electricity among the three buildings. The reason behind the greatest producer is big surface area. As far as solar power is concerned it is directly proportional to the surface area exposed and the projection of sunlight falling on that region. If we observe, then building 1 and building 2 are of similar sizes, still building 2 has produced more electricity than the building 1. The reason which is observed here is the amount of sunlight the buildings are getting. The more clarity can be drawn from the below table:

In total of 34 days of reading of total electricity from building 1 is 143,826; building

Table 5.1: Amount of Sunlight on Specific building and day

	Building 1	Building 2	Building 3
Day 1	3769	7538	11307
Day 2	3693	7386	11079
Day 3	4540	9080	13621
Day 4	3022	6045	9068
Day 5	3572	7145	10718
Day 6	4431	8862	13293
Day 7	4341	8683	13025
Day 8	4677	9355	14033
Day 9	4920	9841	14762
Day 10	4640	9281	13922
Day 11	5251	10502	15753
Day 12	4712	9425	14138
Day 13	4046	8093	12139
Day 14	5801	11602	17403
Day 15	4564	9131	13697
Day 16	4152	8305	12457
Day 17	3440	6861	10322
Day 18	3426	6853	10279
Day 19	4246	8432	12739
Day 20	4341	8683	13025
Day 21	4884	9769	14654
Day 22	4592	9184	13776
Day 23	3866	7732	11598
Day 24	4831	9663	14495
Day 25	5012	10024	15037
Day 26	4901	9802	14704
Day 27	3807	7615	11423
Day 28	3075	6151	9227
Day 29	3227	6455	9683
Day 30	5027	10054	15081
Day 31	4183	8366	12550
Day 32	3914	7828	11742
Day 33	3559	7119	10679
Day 34	3363	6727	10091

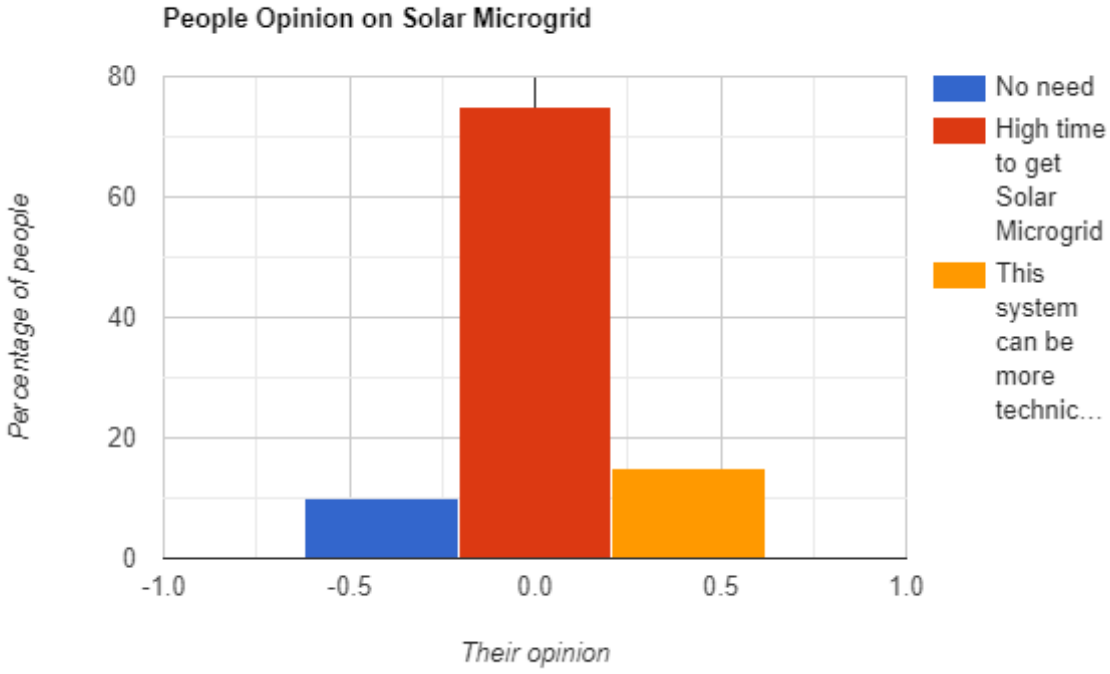

Figure 5.1: Bar Graph on People Opinion vs Percentage of People

2 is 279,652; and that of building 3 is 431,520.

Chapter. 6

Results & Discussion

6.1 System Working

In Simulation we have 3 different buildings, each with a different number of solar panels to generate and evaluate results. The 1st building contains 6 solar panels and the second building contains 12 solar panels, similarly the 3rd building has 18 solar panels. Each building contains an energy storage system and also there is a generator to covert the direct current into Alternating current. In the simulation we have used 2 scripts, 1 script contains all the code and formulas to calculate the required values and amount of energy etc. and the other script helps in loading the isolation and consumption data from the Csv file.

6.1.1 Formulas we used in the simulation -

Efficiency = (330 / 19.5f) / (1000) * 100

Where 330 is the maximum charge capacity of solar panel in watts and 19.5 is the area covered by 1 solar panel -

Total Solar Power (DC)= area * efficiency * Irradiance

where area is the total area covered by the solar panels i.e., total number of solar

panels multiplied by area covered by 1 solar panel (19.5) and the efficiency is the one that we calculated above, irradiance means the isolation data that we load from the Csv.

If the consumption is < the total generation then the battery will store the rest of power generated and will send the required amount to the inverter or else the battery will store 20 percent of the dc and will deliver rest of the 80 percent to the inverter. Then the inverter will turn the dc into ac to deliver to the consumer.

Total AC = DC * 0.95 where DC is the energy delivered by the battery as per the requirement and 0.95 is the efficiency rate.

1	DATE_TIME	PLANT_ID	SOURCE_K	AMBIENT_	MODULE_	IRRADIATI	CONSUMPTION
2	5/15/2020 0:00	4135001	HmiyD2TT	25.18432	22.85751	0	0
3	5/15/2020 0:15	4135001	HmiyD2TT	25.08459	22.76167	0	0
4	5/15/2020 0:30	4135001	HmiyD2TT	24.93575	22.59231	0	0
5	5/15/2020 0:45	4135001	HmiyD2TT	24.84613	22.36085	0	0
6	5/15/2020 1:00	4135001	HmiyD2TT	24.62153	22.16542	0	0
7	5/15/2020 1:15	4135001	HmiyD2TT	24.53609	21.96857	0	0
8	5/15/2020 1:30	4135001	HmiyD2TT	24.63867	22.35293	0	0
9	5/15/2020 1:45	4135001	HmiyD2TT	24.87302	23.16092	0	0
10	5/15/2020 2:00	4135001	HmiyD2TT	24.93693	23.02611	0	0
11	5/15/2020 2:15	4135001	HmiyD2TT	25.01225	23.34323	0	0
12	5/15/2020 2:30	4135001	HmiyD2TT	25.00515	23.63946	0	0
13	5/15/2020 2:45	4135001	HmiyD2TT	24.99302	24.03949	0	0
14	5/15/2020 3:00	4135001	HmiyD2TT	25.01631	24.38414	0	0
15	5/15/2020 3:15	4135001	HmiyD2TT	24.98522	24.35151	0	0
16	5/15/2020 3:30	4135001	HmiyD2TT	24.93773	24.0603	0	0
17	5/15/2020 3:45	4135001	HmiyD2TT	24.8791	23.70979	0	0
18	5/15/2020 4:00	4135001	HmiyD2TT	24.6789	22.58994	0	0
19	5/15/2020 4:15	4135001	HmiyD2TT	24.35193	21.78364	0	0
20	5/15/2020 4:30	4135001	HmiyD2TT	24.06262	21.85252	0	0
21	5/15/2020 4:45	4135001	HmiyD2TT	24.01322	22.30632	0	0
22	5/15/2020 5:00	4135001	HmiyD2TT	24.17711	22.55191	0	0
23	5/15/2020 5:15	4135001	HmiyD2TT	24.30489	22.97949	0	0
24	5/15/2020 5:30	4135001	HmiyD2TT	24.32873	23.45238	0	0
25	5/15/2020 5:45	4135001	HmiyD2TT	24.28921	23.09669	0.000863	50
26	5/15/2020 6:00	4135001	HmiyD2TT	24.08845	22.20676	0.005887	50
27	5/15/2020 6:15	4135001	HmiyD2TT	24.01164	22.35346	0.022282	50

Figure 6.1: Sample Dataset

The solar irradiance is the output of the light energy. It is the power per unit area received from the Sun which is in the form of electromagnetic radiation as measured in wavelength. The unit of solar irradiance is square meter i.e., W/m^2. We are using

this solar irradiance data to calculate the total energy produced by the solar panels by multiplying the irradiance with the area covered by the solar panels. The data in the CSV file is per 15 mins data. The consumption is the load required by the consumer.... i.e., energy demand. The consumption data in the CSV is random data entered. The consumption is getting compared by the energy generated by the solar panels and if the load demand is less than the energy generated then the extra energy produced will get stored in the battery. The energy generated by the solar panels will then be converted into AC power and get delivered to the consumer. The energy generated is the DC current and 20 percent of the DC energy will directly be stored into the battery as backup energy and the rest of the 80 percent will be converted to AC energy for the consumer. Visualization

6.2 Simulation Model & Results

6.2.1 Unity 3D model Simulation before running

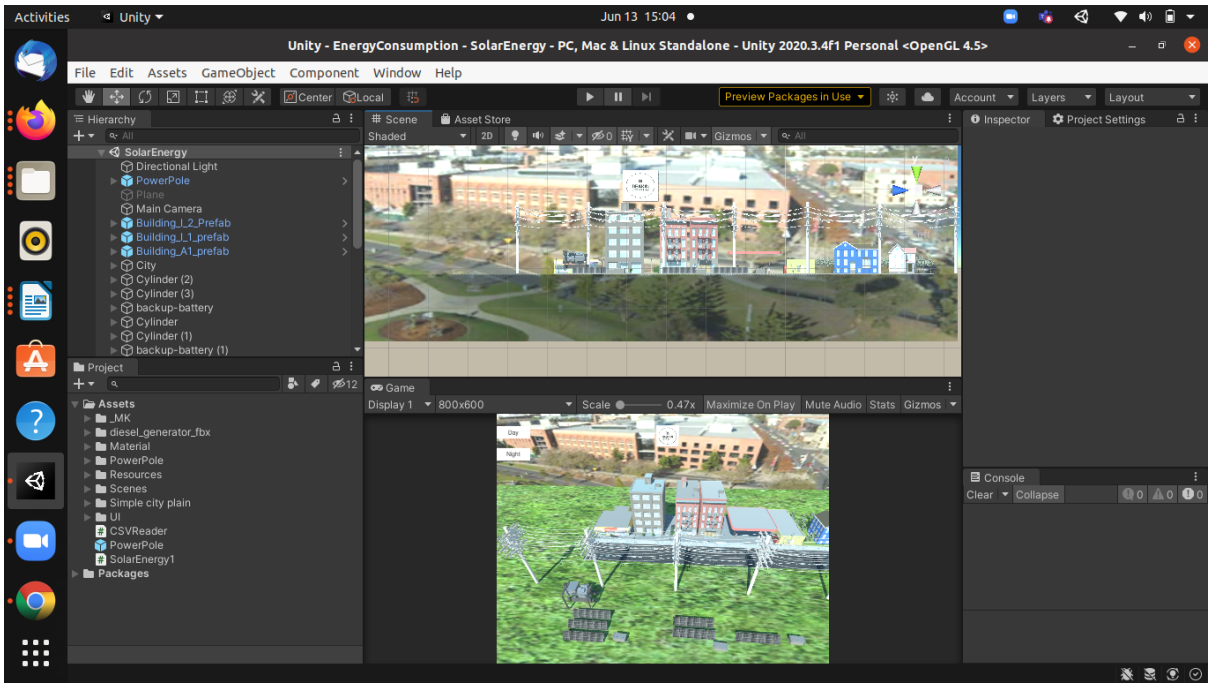

Figure 6.2: System Simulation

This is the screen 6.2we get before starting our digital twin model. This is visualized in the software called as Unity 3D which is primary software used for designing the games. On this software we have feeded with the real-world data which helps us to get the exact simulations of the solar microgrid we want to design. This screen has a column of project which shows us the saved files and also help us in saving our work or graphics. On the right side we have console which is used to show any kind of output or errors which a system can face during its implementation.

6.2.2 Unity 3D model simulation after running

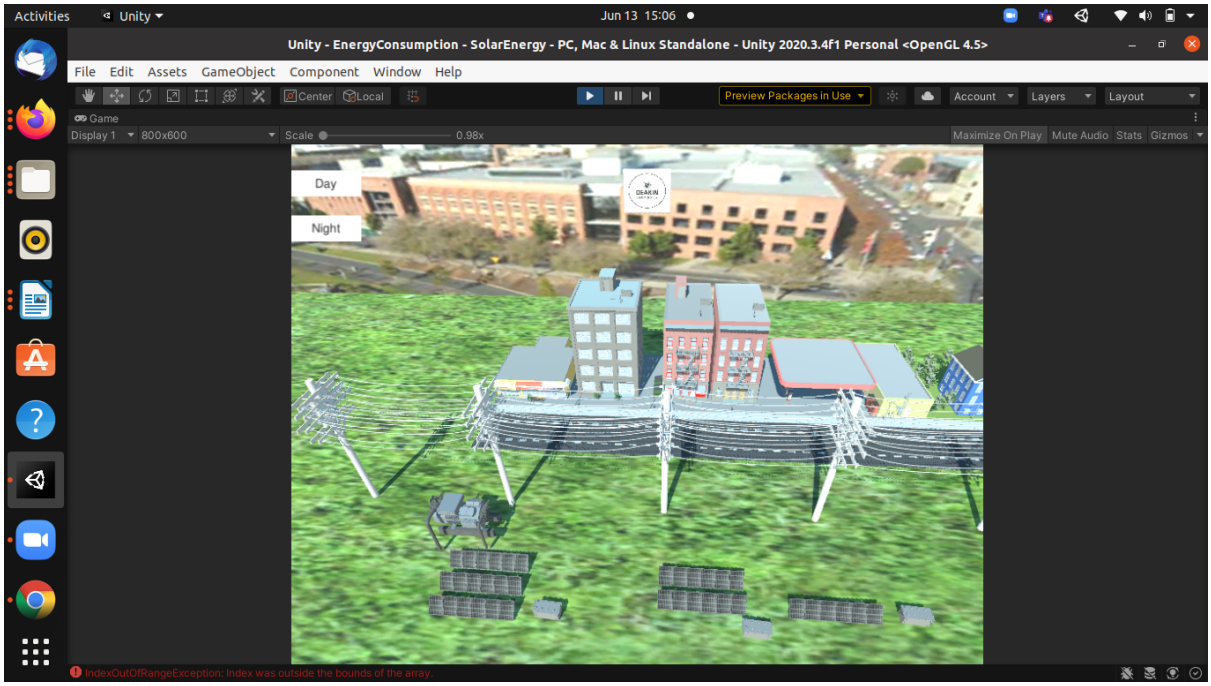

Figure 6.3: System Simulation after running

After we compile our work and run the model, this is the screen we are getting6.3. It consists of the graphical view of the buildings and it also shows the solar panels installed on the site. There is also the day and night button which helps us to visualize the solar panel movement during the day and the night. We have tried to implement this system in a way in which the solar panel changes its direction in night and the next day the panels again face the sun.

6.2.3 Simulation of the System for the Night View

The solar panels will shift their position automatically once we press the night button as there is no sunlight 6.4. This is the one of the most smart systems we have tried to involve in out implementation of this digital twin of the solar microgrid. There are chances that the solar panel might get faulty if the direction is not changed in the night time.

6.2.4 Simulation of the System for the Day View

The solar panels will shift their position to normal after we press the day button as it gets sunny again 6.5.

Figure 6.4: System Simulation after we press the night button

Figure 6.5: System Simulation after we press the Day button

6.2.5 Total energy generated by 6 solar panels for load 1

The graph shows the total energy generated by the 6 solar panels per day for building 1(load 1) 6.6. We can close by pressing the close button on top right corner. This feature gives us an estimate of electricity produced by each load and we can also map the usage of each load accordingly.

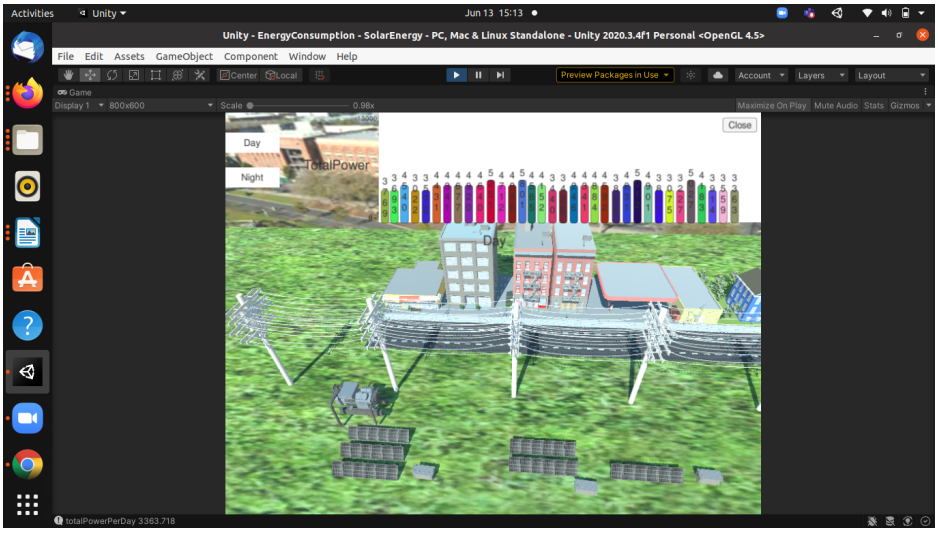

Figure 6.6: Total energy generated by 6 solar panels for Load 1

6.2.6 Total energy generated by 12 solar panels for the load 2

The graph shows total energy generated by 12 solar panels for the building 2(load 2) 6.7. we can close the graph by pressing the close button on the top right corner.

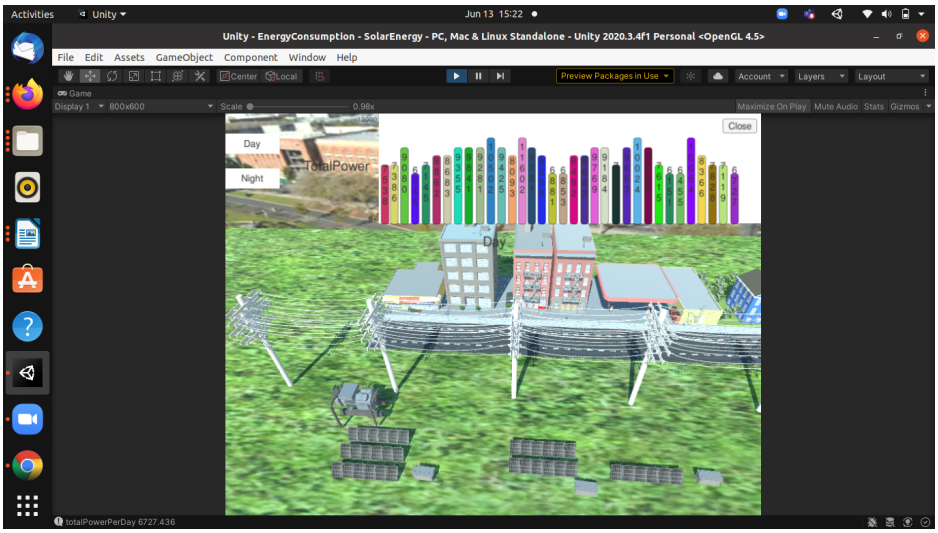

Figure 6.7: Total energy generated by 12 solar panels for Load 2

6.2.7 Total energy generated by 18 solar panels for load 3

The graph shows total energy generated by 18 solar panels for building 3(load 3) 6.8. We can close the graph by pressing the close button.

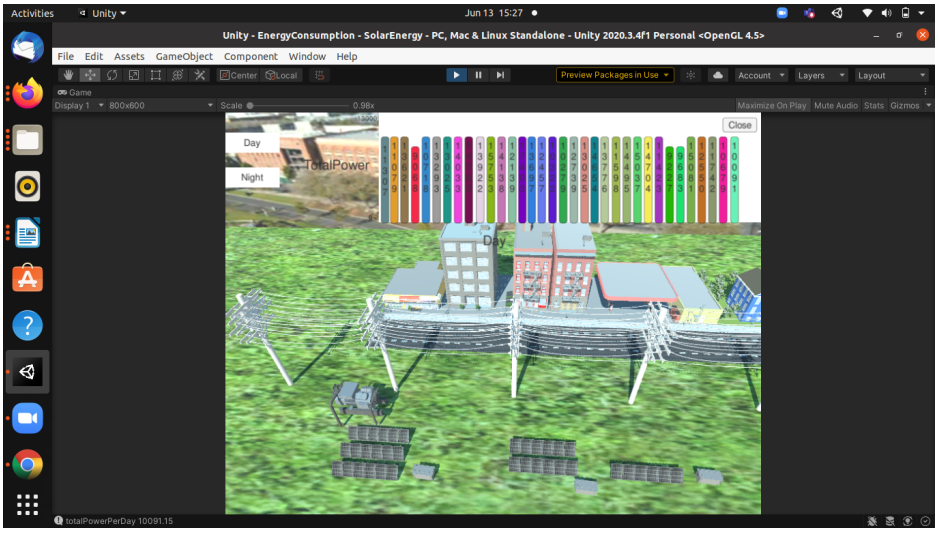

Figure 6.8: Total energy generated by 18 solar panels for Load 3

6.2.8 Microgrid Digital Twin Simulation Elements

The different elements involved in the simulation of this work for microgrid digital twin are as follows:

Load 1

This image shows us the pictorial representation of load 1. The load 1 contains 6 solar panels for which the graph output is shown in 6.6

Figure 6.9: Load 1

Load 2

This image shows us the pictorial representation of load 2. The load 2 contains 12 solar panels to test the output difference between load 1 and load 2 6.10.

Figure 6.10: Load 2

Load 3

This image shows us the pictorial representation of load 3. The load 3 contains 18 solar panels to test the difference between the output for all the 3 loads 6.11.

Figure 6.11: Load 3

Solar panels visualization for Load 1

Solar panels visualization for Load 2

As building 1(load 1) 6.12 and building 2(load 2) 6.13 are small and compact according to our digital twin simulation, the solar panels will obviously be less because of less space availability.

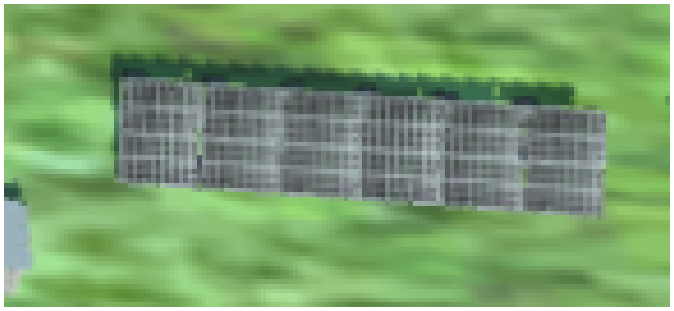

Figure 6.12: Solar Panels for Building 1

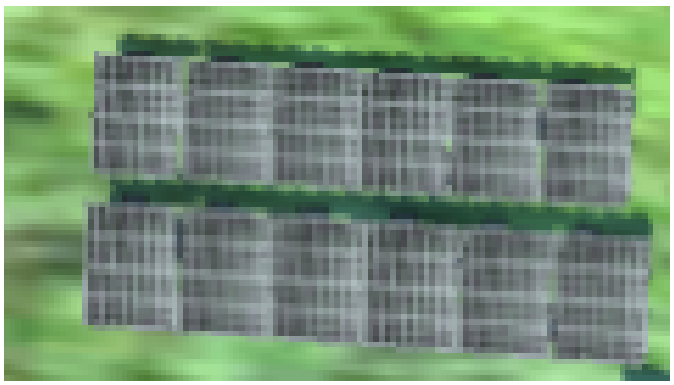

Figure 6.13: Solar Panels for Building 2

Solar panels visualization for Load 3:

As the design of building 3(load 3) 6.14 is bigger as compared to that of building 1 and building 2 so a greater number of solar panels have been installed for building 3(load 3).

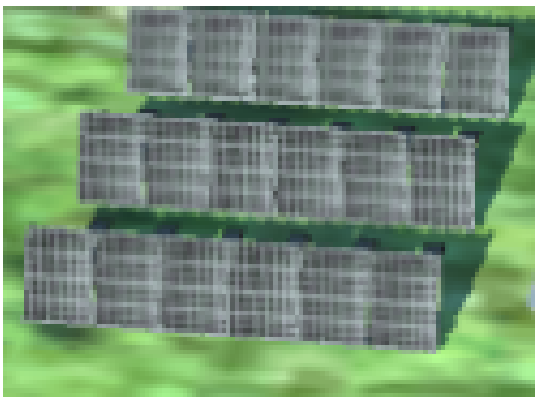

Figure 6.14: Solar Panels for Building 3

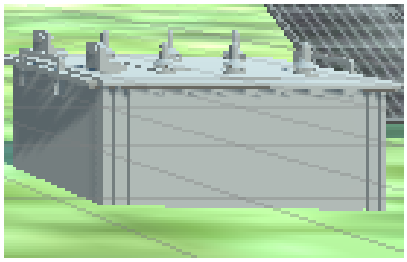

Figure 6.15: Energy Source

Energy Source:

Generator:

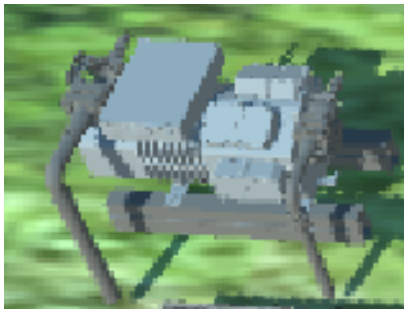

Figure 6.16: Generator

Solar panels simulation for the Night View

We can observe the flipping of the solar panels after we press the night button. This will help us to prevent the solar panels to get faulty.

Output console for the 6 solar panels

This is the console screen of the system which is used to check any error or the final output of the system. The above is the output after pressing 6 in the solar panel 6.18.

Output console for the 12 solar panels

In this screen we get the output from the solar panel after pressing the 12 solar panels for load 2 6.19.

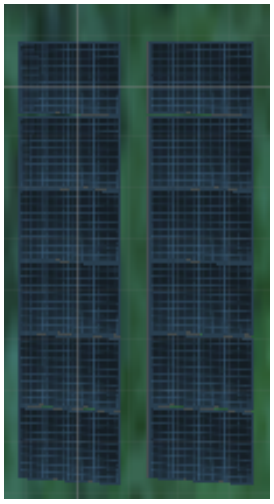

Figure 6.17: Solar panels after pressing night button

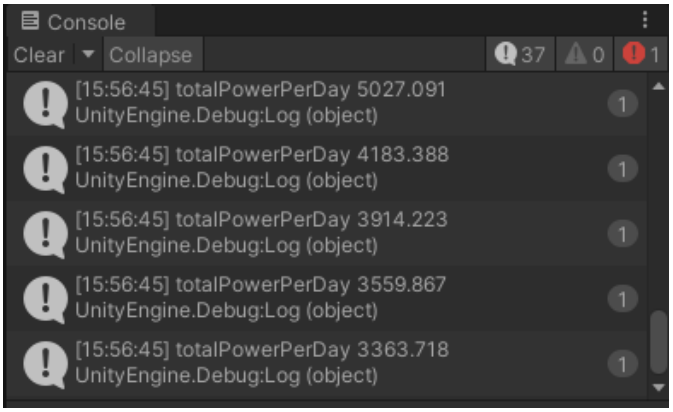

Figure 6.18: Output console after pressing the 6 solar panels

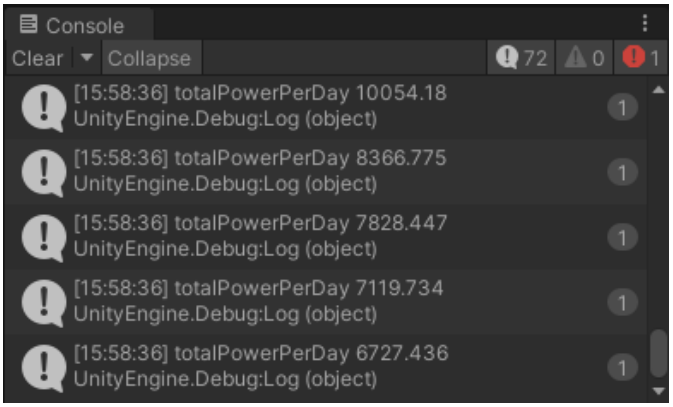

Figure 6.19: Output console after pressing the 12 solar panels

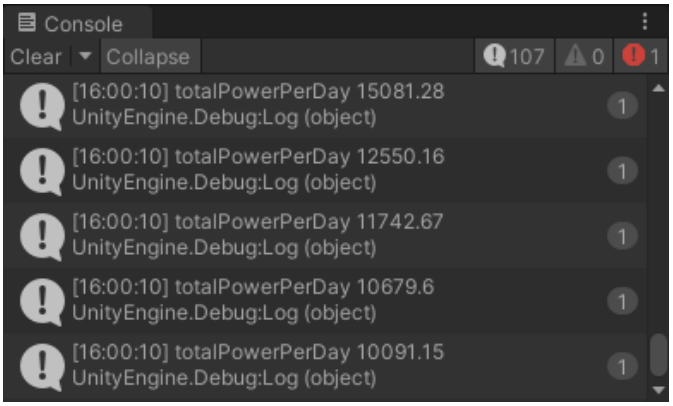

Figure 6.20: Output console after pressing the 18 solar panels

Output console for the 18 solar panels

Similar to the above consoles screen, this is the output shown by our digital twin system after pressing 18 solar panels for load 3 6.20.

6.3 Unity 3D Elements

Different Unity 3D elements which plays a very important role in this thesis and digital twin simulation are as follows:

C# files used in the simulation

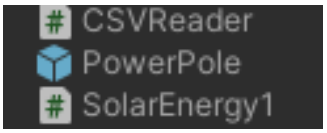

Figure 6.21: C# files used in the simulation

CSVReader file is used to read solar irradiance data from the CSV file while SolarEnergy1 is used to get the output. We have used a C# script to get the data set read for making our digital twin more effective

Hierarchy window screenshot (all the models used in the simulation)

This image shows the hierarchy of the complete system's visualization of the digital twin of solar microgrid, this window contains all the elements used in this simulation such as generators, solar panels, loads, storage systems etc 6.22.

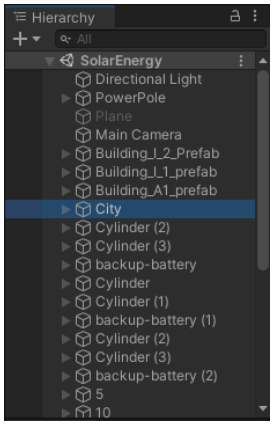

Figure 6.22: Hierarchy window screenshot

CSV Reader Function

```
public List<SolarPowerEnergy> spE = new List<SolarPowerEnergy>();

public List<float> irradiation = new List<float>();
public List<float> consumption = new List<float>();
void Awake()
{
    Debug.Log("Read the CSV file");
    TextAsset DataCSV = Resources.Load<TextAsset>("Plant_1_Weather_Sensor_Data");
    string[] line = DataCSV.text.Split(new char[] { '\n' });

    for (int i = 0; i < line.Length; i++)
    {
        string[] part = line[i].Split(new char[] { ';' });

        SolarPowerEnergy solarPowerEnergy = new SolarPowerEnergy();
        solarPowerEnergy.IRRADIATION = part[0];

        spE.Add(solarPowerEnergy);

    }
    float ap,consump;
    for (int i = 0; i < spE.Count; i++)
    {

        string[]  part1 = spE[i].IRRADIATION.Split(new char[] { ',' });
        {
          float.TryParse(part1[5], out ap);
        float.TryParse(part1[6], out consump);
        irradiation.Add(ap);
        consumption.Add(consump);
             }
}
```

Figure 6.23: CSV Reader Function

This is the script we have used for reading the dataset for our digital twin system. This script has been written in C# language 6.23.

6.3.1 Different formulas used for Solar Energy calculation

This screen shows us the algorithm which we have used for calculating the solar power produces by the different solar panels installed on the different buildings. This can be termed as the brain of the system as this will only help us to know the exact amount of power being produced by the solar panels 6.24.

```
float[] pdcstc1 =
{
    2370,
    2800,
    3000,
    3300,
    3300
};
float[] dirt1 =
{
    0.97f,
    0.95f,
    0.93f,
    0.98f,
    0.98f
};
float[] invertor1 =
{
    0.92f,
    0.94f,
    0.93f,
    0.98f,
    0.98f
};

public Image[] graphHelper,graph;

float[] mismatch1 =
{
    0.97f,
    0.91f,
    0.92f,
    0.97f,
    0.98f
};
float[] temperature1 =

    0.87f,
    0.81f,
    0.92f,
    0.77f,
    0.98f
};
```

Figure 6.24: Different formulas for Solar Energy calculation

Chapter. 7

Threats to Validity

After implementing the digital twin of solar microgrid system, we understood that there can be some threats to validity to our proposed idea. These threats can be external as well as internal. But looking at the threats, they seem to be very less when we compare them with the usability of our system. Sustainable energy is the need of the hour and it is something that should be grown at a fast pace to create a better place to live in. Electricity is one of the most sustainable form of energy but if we produce that electricity from non renewable sources then it seems to be of no use. That is the main issue we tried to explore with the help of solar microgrid and to have a proof of concept, we have worked o creating a digital twin of solar microgrid. A microgrid is used for generating hydro electricity, electricity from the wind and electricity from the solar power. In this project we majorly focused on deriving electricity from the solar power because of its high availability and high feasibility. Installing the solar panels which are used to capture the solar energy needs only an open space with access to great amount of sunlight. Unlike windmills solar panels do not need too much of big space to be installed and they do not carry a risk factor of affecting the nearby population from high wind or from heavy rainfall.

The threats can be discussed in two ways i.e., internal threats and external threats when we talk about the solar microgrid system. Starting with the external threats, solar panel works great in sunlight but if they get less sunlight then some threshold value, their performance can be hindered. This is a very important threat as the solar panels should be installed on such a site which has very less projection of shadow. One more external threat which needs to be taken care at sites is that it should be installed by taking care or observing the birds activities, as interaction of panels with the birds can also defect the panel and thus the performance of the overall system will be disturbed. Talking about the internal threats, there are many things including batteries, chillers, etc. which are installed on the site apart from the solar panels. There is a chance that these equipment might get faulty and can hinder the performance of the overall system. But in the system

we tried to simulate via digital twin concepts, has more utility and these threats can be ignored if we observe the performance of the system.

Chapter. 8

Conclusion & Future Work

8.1 Conclusion

In this thesis, we have tried to implement the digital twin for the solar microgrid. Microgrid is generating electricity from water, air or from the solar power. In this thesis we majorly focused on solar power electricity because of its high feasibility. If we want to generate hydro power then we need to have a big dam full of water and there should be a turbine attached to it. Similarly for generating electricity from the wind, we need to have ample of open space where the windmill can be installed and electricity can be derived. Unlikely, this is not the case with the utilization of solar energy. We just need an open space where we have access to the sunlight and we will be generating great amount of electricity. There are also not safety concerns attached to solar electricity unlikely from the wind mill or the wind energy used for electricity generation. We also discussed about the drawbacks of the conventional electricity supply and why generating electricity from the solar power microgrid is the need of the hour. Cost is a main factor which is used to term solar energy as the best form of energy compared to the conventional source of energy but there are other factors too. We came to know that supplying electricity to mobile areas with the help of the conventional method, it has been observed that the supplied electricity is not clean which means it has too many fluctuations and too much of energy loss on the way is also taking place which is ultimately polluting the environment. This is not the case with the solar based microgrid which we have tried to simulate for this thesis. We used a proper visualization tool which helped us to keep a check and also helped us to observe the outputs the solar microgrid will gives us after real time installations.

8.2 Future Work

In future, we would like to automate the complete system and make the system more intelligent. We will incorporate our digital twin with the Machine Learning and Artificial Intelligence algorithms and try to build in an intelligent digital twin system. The system should have a decision-making capability which can only be introduced by using the help of system training techniques. The digital twin system which we have implemented in this thesis, should also have a good visualization in showing the output which can be improved further with the help of many visualization tools available in the market like power app platform by Microsoft. This system can also be taken to CRM model i.e., Customer Relationship Model which will give us all the insights happening in our system. This will help us to analyze the great amount of data which is produced by the solar microgrid and many interesting insights can be drawn from this data.

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Appendix

Table 8.1: Dataset used in the simulation

DATE_TIME	PLANT_ID	SOURCE_KEY	AMBIENT_TEMPERATURE	MODULE
15-05-2020 00:00	4135001	HmiyD2TTLFNqkNe	25.18432	
15-05-2020 00:15	4135001	HmiyD2TTLFNqkNe	25.08459	
15-05-2020 00:30	4135001	HmiyD2TTLFNqkNe	24.93575	
15-05-2020 00:45	4135001	HmiyD2TTLFNqkNe	24.84613	
15-05-2020 01:00	4135001	HmiyD2TTLFNqkNe	24.62153	
15-05-2020 01:15	4135001	HmiyD2TTLFNqkNe	24.53609	
15-05-2020 01:30	4135001	HmiyD2TTLFNqkNe	24.63867	
15-05-2020 01:45	4135001	HmiyD2TTLFNqkNe	24.87302	
15-05-2020 02:00	4135001	HmiyD2TTLFNqkNe	24.93693	
15-05-2020 02:15	4135001	HmiyD2TTLFNqkNe	25.01225	
15-05-2020 02:30	4135001	HmiyD2TTLFNqkNe	25.00515	
15-05-2020 02:45	4135001	HmiyD2TTLFNqkNe	24.99302	
15-05-2020 03:00	4135001	HmiyD2TTLFNqkNe	25.01631	
15-05-2020 03:15	4135001	HmiyD2TTLFNqkNe	24.98522	
15-05-2020 03:30	4135001	HmiyD2TTLFNqkNe	24.93773	
15-05-2020 03:45	4135001	HmiyD2TTLFNqkNe	24.8791	
15-05-2020 04:00	4135001	HmiyD2TTLFNqkNe	24.6789	
15-05-2020 04:15	4135001	HmiyD2TTLFNqkNe	24.35193	
15-05-2020 04:30	4135001	HmiyD2TTLFNqkNe	24.06262	
15-05-2020 04:45	4135001	HmiyD2TTLFNqkNe	24.01322	
15-05-2020 05:00	4135001	HmiyD2TTLFNqkNe	24.17711	
15-05-2020 05:15	4135001	HmiyD2TTLFNqkNe	24.30489	
15-05-2020 05:30	4135001	HmiyD2TTLFNqkNe	24.32873	
15-05-2020 05:45	4135001	HmiyD2TTLFNqkNe	24.28921	
15-05-2020 06:00	4135001	HmiyD2TTLFNqkNe	24.08845	
15-05-2020 06:15	4135001	HmiyD2TTLFNqkNe	24.01164	
15-05-2020 06:30	4135001	HmiyD2TTLFNqkNe	23.97673	
15-05-2020 06:45	4135001	HmiyD2TTLFNqkNe	24.21899	
15-05-2020 07:00	4135001	HmiyD2TTLFNqkNe	24.5374	
15-05-2020 07:15	4135001	HmiyD2TTLFNqkNe	24.81596	
15-05-2020 07:30	4135001	HmiyD2TTLFNqkNe	24.98879	
15-05-2020 07:45	4135001	HmiyD2TTLFNqkNe	25.21618	
15-05-2020 08:00	4135001	HmiyD2TTLFNqkNe	25.41951	
15-05-2020 08:15	4135001	HmiyD2TTLFNqkNe	25.95908	
15-05-2020 08:30	4135001	HmiyD2TTLFNqkNe	26.43078	
15-05-2020 08:45	4135001	HmiyD2TTLFNqkNe	26.83183	
15-05-2020 09:00	4135001	HmiyD2TTLFNqkNe	27.62097	
15-05-2020 09:15	4135001	HmiyD2TTLFNqkNe	27.98836	
15-05-2020 09:30	4135001	HmiyD2TTLFNqkNe	27.51673	
15-05-2020 09:45	4135001	HmiyD2TTLFNqkNe	27.45011	
15-05-2020 10:00	4135001	HmiyD2TTLFNqkNe	28.63219	
15-05-2020 10:15	4135001	HmiyD2TTLFNqkNe	28.76891	
15-05-2020 10:30	4135001	HmiyD2TTLFNqkNe	29.35144	
15-05-2020 10:45	4135001	HmiyD2TTLFNqkNe	28.85471	
15-05-2020 11:00	4135001	HmiyD2TTLFNqkNe	29.41082	
15-05-2020 11:15	4135001	HmiyD2TTLFNqkNe	30.21606	
15-05-2020 11:30	4135001	HmiyD2TTLFNqkNe	30.28707	
15-05-2020 11:45	4135001	HmiyD2TTLFNqkNe	30.81105	
15-05-2020 12:00	4135001	HmiyD2TTLFNqkNe	31.30538	