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CONTROL AND OPTIMIZATION OF ISLANDED MODE MICRO GRID

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CONTROL AND OPTIMIZATION OF ISLANDED MODE MICRO GRID

Ada Modu Mikro Şebekelerin Kontrol ve Optimizasyonu

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ABSTRACT

Electrical energy plays a significant role in society since it maintains a high standard of living and stable economic development. Electric energy consumption has been gradually increasing in recent history, and this need is expected to increase more in the future. The majority of power today is generated by the combustion of fossil fuels, and there are considerable worries about the associated emissions. Renewable energy sources emerged as a feasible substitute for ecologically damaging ones. However, renewable energy sources have significantly unpredictable environmental circumstances when it comes to power generation and cannot be immediately integrated into the existing electrical system. The increased usage of renewable energy systems in recent years has increased the necessity of establishing microgrids. Energy is used where it is produced in microgrids. As a result, transmission and line losses are reduced to zero. At the same time, the micro grid model eliminates the negative impacts of commercial plants that disturb electricity standards, and more efficient and dependable grids are frequently built. A micro-grid is a grouping of micro-sources with a load and an optional energy device inside a certain area. The microgrid is normally operated in one of three modes: autonomous, non-autonomous, or dual. A micro-grid should generate and control its own energy in an independent operation.

In this study, control applications on microgrids and the hierarchical control approach applied for microgrid architectures are investigated from a literature review. The pros and cons of these control methods are compared with one another. The key feature is to retain the frequency and voltage values of an islanded micro grid system within acceptable limits. Clean and green energy will be provided to the consumers of Büyükada (project's site). The island will be self-sufficient for its energy needs.

ÖZET

Elektrik enerjisi, yaşam kalitesine etkisi ve istikrarlı ekonomik gelişmeyi sağladığı için toplumda hayati bir role sahiptir. Elektrik enerjisine olan talep yakın tarih boyunca istikrarlı bir şekilde artmış ve elektriğe duyulan talebin gelecekte de hızla artmaya devam edeceği ön görülmektedir. Halen günümüzde elektriğin çoğu fosil yakıtların yakılmasıyla üretilirken, ortaya çıkan emisyon konusunda ciddi endişeler bulunmaktadır. Yenilenebilir enerji kaynakları, çevreyi yoğun olarak kirleten enerji kaynaklarına alternatif olarak ortaya çıkmıştır. Bununla birlikte, yenilenebilir enerji kaynakları, güç çıktısını hesaba katarken, üretimin çoğunlukla çevre koşullarına bağlı olan ve doğası gereği doğrudan mevcut elektrik şebekesine dahil edilemeyen sistemlerdir. Son yıllarda yenilenebilir enerji sistemlerinin kullanımındaki artış, mikro şebekeler üzerinde yapılan çalışmaların öneminin artmasına da neden olmuştur. Mikro şebekelerde enerji üretildiği yerde tüketilmektedir. Bu, iletimde bir kesintiye ve hatlarda güç kayıplarına neden olur . Ticari santrallerin güç kalitesini bozan olumsuz etkileri mikro şebeke modeli ile ortadan kaldırılabilmekte ve çoğu zaman daha verimli ve güvenilir şebekeler kurulabilmektedir. Bir mikro şebeke, bir alan içinde bir yük ve isteğe bağlı bir enerji cihazı ile toplu olarak mikro kaynakların birleştirilmesinden oluşurken, genellikle otonom, otonom olmayan veya ikili işletimde çalıştırılır. Otonom bir operasyonda, bir mikro şebeke enerjisini üretmeli ve aynı zamanda üretimin kontrolünü de sağlamalıdır.

Bu çalışma kapsamında, mikro şebekeler üzerindeki kontrol uygulamaları ve mikro şebeke mimarileri için uygulanan hiyerarşik kontrol yaklaşımı literatür taraması yapılarak incelenmiştir. Bu kontrol yöntemlerinin artıları ve eksileri birbirleriyle karşılaştırılır. Anahtar özellik, adalı bir mikro şebeke sisteminin frekans ve voltaj değerlerini kabul edilebilir sınırlar içinde tutmaktır. Seçilen çalışma sahası olan Büyükada'da elektrik tüketicilerine temiz ve yeşil enerji sağlanması hedeflenmiştir. Çalışma sonucuna göre, Büyükada, enerji ihtiyacı için kendi kendine yetebilecektir.

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ABBREVIATIONS

- Renewable Energy Sources (RES)
- MicroGrid (MG)
- Distributed Energy Resources (DER)
- Distributive Generation (DG)
- Energy Storage System (ESS)
- Conventional Energy Resources (CER)
- Point of Common Coupling (PCC)
- Multi Agent System (MAS)
- Maximum PowerPoint Tracking (MPPT)
- Phase Locked Loop (PLL)
- Micro Grid Central Controller (MGCC)
- Artificial Neural Network (ANN)
- Recurrent Neural Network (RNN)
- Long-Short Term Memory (LSTM)

1. INTRODUCTION

Renewable energy sources accounted for 16% of total world energy consumption. Biomass energy accounts for 10%, hydroelectricity accounts for 3.4%, and other renewable energy sources such as hydro, advanced biomass, solar, wind, biofuels, and geothermal account for 3%. Renewable energy sources that fulfill home energy demands can supply energy with practically zero emissions of air pollutants and greenhouse gas emissions.

Environmental protection, energy security, and economic development concerns, colloquially known as the "three E" (Environment, Energy, and Economics), are linked global challenges of the contemporary era. People are becoming more conscious that the challenges facing the energy sector are growing more serious. Power system operations are becoming more labor-intensive, demanding more research into energy security, economic development, and efficiency, so setting the framework for a modern concept of "Smart Grid" (SG).

Photovoltaic (PV) technology is one of the distributed generations. PV is being used all over the world to provide the basic energy demands of rural communities that are not linked to the distribution network. Batteries are used to store the energy generated by the PV system. The PV module/array operation characteristics are researched across a wide variety of operating situations and physical factors.

The structure of the electric power system has recently changed, and electricity generation is now geared toward Distributed Generation (DG). Although worries about environmental characteristics of traditional power generating are stated as causes for this shift, another critical objective has emerged.

A microgrid (MG) is a vital and necessary component of a smart grid. MGs are intended to increase energy efficiency, reliability of energy and power production systems, and CO_2 emissions. A microgrid is a group of loads in which micro-sources generate both energy and heat independently. Most micro sources must be electronically managed in order to work as a stand-alone and fully integrated system. An MG connects native distributed power loads to distributed energy sources such microturbines, wind turbines, photovoltaic (PV), and low-voltage storage devices (LV). With several micro sources connected via the distribution mechanism, additional difficulties such as system stabilization, produced power quality, and operational network must be handled using proven control methodologies on LV/MV.

There are a total of 9 islands near the Anatolian part of Istanbul. 5 of them are operational for people to visit, live and explore. Near Istanbul, in the Sea of Marmara, an island named 'Büyükada' is the largest of the Princes' Islands with an area of about 2 square miles (5 square kilometers). It is officially recognized as a neighborhood in the Adalar (Islands) district of Istanbul Province, Turkey. The total population of all the islands is around 16k. Currently, energy is supplied from the Asian part to fulfill the energy requirements. Büyükada has an average sunshine duration of about 7.5 hours [26] and an average wind speed of $7.13 m/s^2$ [27]. Both Photovoltaic Energy (PV Panels) and Wind Turbines are good options for energy production.

1.1 Conventional energy system challenges and Importance of micro-grids

The majority of energy around the world is being produced by burning fossil fuels and using transformers and other energy storage and control system being transmitted to the community by national grids. The technology though sounds smooth yet bears environmental drawbacks. Burning the fuel may produce the energy but also release oxides and dioxides into the atmosphere which causes climate change.

To balance out the climate challenge renewable energy resources are the current research fields. Though renewable energy resources are reliable the need to have a comprehended energy storage system and a wide range transmission system for uninterrupted energy supply to the consumer.

Another drawback of conventional energy is large assets and long miles of above-ground wires for transmission which requires quite a work to maintain and manage. During a natural disaster or any energy cut down results in black out of the community for long hours.

Microgrids are a possible alternative for energy supply as they are capable of providing the backup power supply in case of emergency and also they can be the autonomous source of energy (for a specific area or community). They are efficient, low-cost, green (and clean) energy resources. They are a sustainable energy source for consumers and make energy management easy and accessible to all.

1.2 Literature Review

R. H. Lasseter [16] discusses microgrid core architecture, control and protection, and energy management.

T. Ackermann and colleagues [17] suggest distributed generation (DG). It has investigated the important issues and detailed and explained distributed power generation. "Distributed generation" was defined by them. Technical terms like distributed capacity, distributed resources, and distributed utility have also been explored.

R. H. Lasseter et al [18] studied MG technologies in depth in their work related to the research project "The Consortium for Electric Reliability Technology Solution (CERTS)," which provided the justification for the formation of MG. This research also educates readers on the technologies used to jumpstart distributed generation. The researchers have handled virtually all of the important distributed energy resources, including storage, device load control, and heat recovery. The Micro Grid system's major characteristic is that its power sources are linked to controllers.

The work by N.Hatziargyriou et al [19] discusses continuing research and development as well as a demonstration of the function of microgrid operation, which is currently used in many industrialized nations such as Europe, Japan, the United States, and Canada. MGs contribute to the highly decentralized coordination of DERs (distributed energy resources). As a result, MGs reduce the control pressure on the grid. According to the authors, microgrids are LV locally-controlled clusters of DERs that serve as a lone producer or both in electric and energy markets on behalf of the grid. A microgrid runs in its local distribution network securely and effectively; nonetheless, it is susceptible of "islanding."

S. Chowdhury et al. [20] investigate the fundamental concept, producing technologies, impacts, operation, control, and management features, as well as economic feasibility and market participation problems of MG and active distribution networks. Microgrids are referred to as active distribution network systems by the authors because when distributed energy resources are linked into power systems, the distributed network becomes active.

H. Jiayi et al. [21] investigated the basic concepts of MGs and their active distribution networks, as well as their needs, technical advantages and disadvantages, and other management and operational difficulties. The authors outline the main principles for operating numerous DER technologies used in Microgrid and its active distribution networks, as well as how they affect the whole Microgrid idea. Microgrids have a substantial influence on both the main grid and its customers. In this study, we identified the technological, environmental, and monetary benefits of MG. Microgrid security systems, as well as the development of electronic interfaces for Microgrids, their micro sources, controllers, power quality, Microgrid dependability challenges, and distribution networks, are comprehensively investigated.

In this work, M. Barnes et al [22] present a synopsis of global MG activities. The authors have given a brief description of the structure of the MG. Following an assessment, the hardware range and control options for Microgrid operation are presented. The research evaluates and emphasizes the operational concepts and critical components of prior research and field operations.

In their work, F. Martin-Martnez et al. [23] prepared a review of the literature on MGs. The writers reflect the core principles, organization, and architecture of MG. This article provides an in-depth study of each MG physical layer. The research goes into AC and DC MG functioning, DC voltage measurement, and comparisons of various technologies involved in the MG concept.

D. Olivares et al. [24] describe MG control approaches. This research investigates significant challenges to the Microgrid control system, as well as a discussion of cutting-edge control approaches and trends, as well as a thorough assessment of important control ideas (e.g., droop control, model predictive control, multi-agent systems).

A. Zafeer et al. [25] defined several types of MG. The paper goes through methods as well as simulated results. The results were obtained by coordinating energy loads and sources inside a single MG mechanism.

Fellow, IEE Professor Emeritus Robert H. Lasseter presented a control technique for distributed generation in combination with CHP in a MG in [9].

Zhenhua Jiang, a Senior IEEE member, proposed using a drop control approach to regulate power-sharing and voltage between parallel inverter-interfaced in an islanding operation in [10].

In [11], Rashad M Aymen Chaouachi and Ken Nagasaka examined several control approaches for the transient dynamic response of two G next to one other. If a large disturbance occurs in the main grid, the automatic gain control modifies the operation mode quickly.

Rashad M. Kamel, Aymen Chaouachi, and Ken Nagasaka explored MG stability based on active and reactive power import and export from or to the main grid utilizing active and reactive power regulation techniques in [12].

In [13], Manohar Chamana and Stephen B. Bayne developed another method for switching between the main grid and MG utilizing the master-slave control technique.

Li Bin, Bao Hailong, and Chenyao [14] investigated the regulation and coordination of changes in DG, load, and structure in a MG, as well as power quality, under various system disruptions.

In reference [15], Gelu Gurguiatu1, Ionel Vechiu, and Toader Munteanu proposed an active power conditional (APC) control function as an interface between renewable energy sources and G for improving power quality via the phase-lock loop. (PLL).

1.3 Examples of µG

Microgrids are a new concept in energy systems yet they behold the future of our energy management. There are 4500 µG around the world and the number is increasing periodically [83]. Some of the MG examples [83] are islanded mode MG in Zhangbei-china [4], Kythnos- Greece [5], Barcelona-Spain [6], Japan (Kyushu; Kuroshima, Takeshima, Nakanoshima, Suwanosejima, Kodakarajima, and Takarajima) [7], Maldives [8], Philippines [84], Japan [85], Indonesia [86], Australia [87], and USA [88].

All of the MGs described above are solar and wind-powered, with an energy storage system comprised of lead or lithium-ion batteries and diesel generators. Some utilities have bidirectional energy flow connections to the main grid. The existing examples not only give validation of the MG idea, but also meet the electrical demands of remote islands and geographically challenging places.

Based on the literature, the goal of this project is to create a simulation model of a microgrid powered by renewable resources (solar, wind, and biomass) for Büyükada's energy demands. The micro grid will include islanded mode operating attributes, allowing it to work autonomously for the island's energy supply. A grid-connected mode is also added to optimize the system by injecting extra energy into the national grid, so transferring some of the demand away from fossil fuels and lowering the cost of the MG system.

1.4 Real-life challenges for microgrid challenges

A total of 9 islands near Istanbul are located. Currently, they are powered by electricity from Anatolian Istanbul. The largest of them BÜYÜKADA is mostly visited and has the potential for renewables like solar as it gets an approx. of 7hours -8hours of sunshine and a wind speed, an approx. of $8m/s^2$.

Microgrids are small energy stations that are usually used as a backup to supply uninterrupted power supply to the consumers. They are mostly powered by renewables like Solar, Wind, Biomass, etc. MG's can be used as the main energy supply utility for a specific area. Generally, the energy flows from a grid to the utility end but MG provides a multi-directional flow of energy. This property of MG gives birth to too many challenges. Some of them are explained below.

Uncertainty: MG's are usually powered by renewables. Though renewable energy resources are environmentally friendly in electricity generation their erratic and seasonal nature may end up in insufficient energy supply during peak hours.

Size: MG's are smaller energy supply units that are efficient as backups. But in the case of islanded mode where MG is solely responsible for power supply relatively smaller capacity may cause the fickle electrical supply.

Multi-source complication: As mentioned earlier that MG is renewably operated and may be connected either to the national grid or a generator for backup but the presence of different power sources makes the protection complicated as all the systems need to maintain a 50 Hz – 60 Hz frequency to operate smoothly.

Switching: MG’s are a greater energy backup source but for them to operate smoothly they need to detect the fault faster and switch to control mode to guarantee the power supply continuity.

Wiring: Although bidirectional energy flow appears to be more feasible, it requires a network of wire for an MG to function effectively. Every load must be connected to one active source and one backup source at all times. Another network of wire is required to transfer electricity from the MG to the mains.

Bi-directional (2-D) current flow: Another issue in system control is bi-directional power flow in an MG's feeders. As power flows from both sources towards the load, it is possible that power flows in the other way.

Protection system: In case of fault of any sort, MG must be capable of protecting itself as well as the connected load from the surge. Protection systems are assigned the tasks of isolating the faulty part from the rest of the system and ensuring an uninterrupted power supply.

Energy balance: Controlling the energy balance in MG is one of the major control architecture challenges. Seamless transition from islanding to main control, load management, tie flow, and coordinated operation with protection relay is MG’s crucial characteristics for an efficient energy balance.

Communication network: Most MG’s follow hierarchical layered control with operational commands flowing bi-directionally. This makes the control architecture needs to be more quick and spontaneous to determine and act in a specific direction. The more layers we add to the communicational control architectures; the more delays will be introduced into the system which automatically lowers the overall efficiency of the system.

2. MICROGRID AND DISTRIBUTED GENERATION

The current electrical energy grid approach is to deliver energy from source to sink i.e.: from the generation to the load (consumer). The electrical grid system can be divided into 3 sub-categories namely: The generation, The transmission, and The distribution shown in Figure. 2 (a)

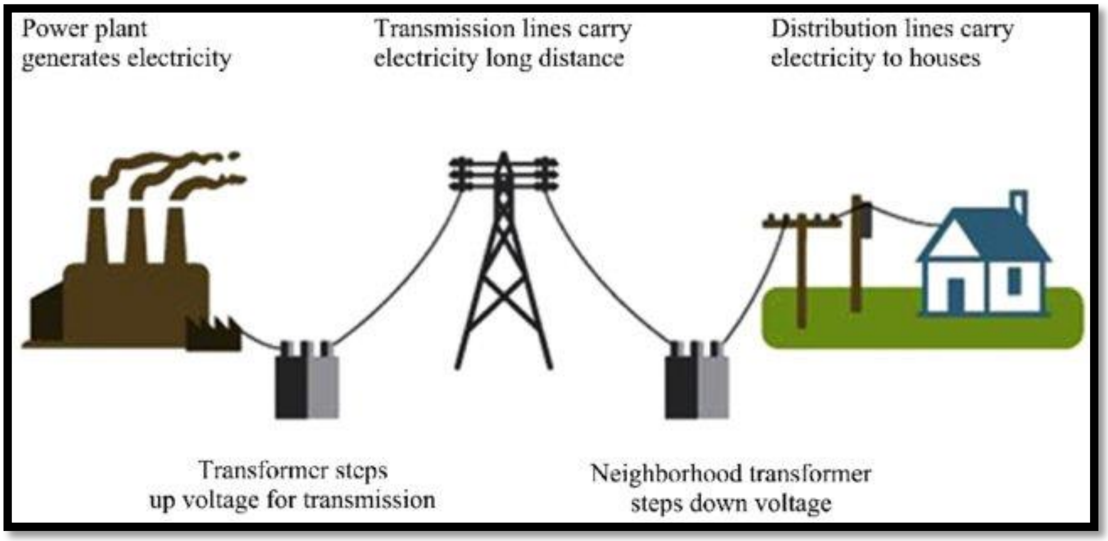


Figure.2 (a) From Generation to Utilization [28]

The generation subsystem consists of high-capacity electrical generation plants. They could have both renewable energy resources like solar and wind as well as non-renewable energy resources like coal and gas. The generated power is then transmitted using a transmission system consisting of step-up transformers and long transmission lines. Then the distribution system plays its part by use of a step-down transformer and distribution lines. This well-established approach is in use for years now and sounds convenient too but it has major drawbacks that need to be dealt with in the future. To start with most generation consists of Non-renewable energy resources usually coal or gas which releases abundant CO_2 into the atmosphere causing to increase the pollution and a rise in Earth’s temperature. Nuclear generation sounds promising but it requires critical handling to avoid any haphazard. Aside from generation problems, it deals with transmission problems too. The load usually is at a distance from the generation which requires high maintenance all the time. Adding the 6% to 8% line losses during transmission and distribution of the generated energy [29]. The complicated infrastructure and aged technology, which can result in blackouts, add to the system's drawbacks. Finally, the building of new generating stations, transmission lines, and distribution systems to supply power to a region is a process that requires compelling economic and profit-making reasons. In other words, because it is not viable for utility suppliers, rural and isolated places are frequently not "electrified."

All of the problems listed above have prompted individuals to seek solutions that would repair and improve the present system. Many of these concerns have been addressed by the introduction of distribution generating (DG) units. DGs are small in size and have a restricted power producing capability as compared to centralized generating units. Because DGs are modular, they may be placed on-site, at the load center. They are employed in parallel with the utility grid or as autonomous generators to guarantee that loads experience minimum or no downtime (UPS), to "energize" remote areas, to enhance power quality for sensitive loads, and to increase overall power system efficiency. DG units that generate energy from renewable sources like as wind, solar, geothermal, tidal, biomass, and hydrogen are becoming more popular. Higher penetration of DG units is projected in the near future, according to a study of future energy demand and supply forecasts [30]. Increasing DG penetration, ownership diversity, and autonomous operation may result in a range of operational conditions inside the electrical grid, including reverse power flow, excessive voltage rise, increased fault levels, harmonic distortion, and stability difficulties. The broad usage of DG, as well as its geographical distribution and size, will have a substantial impact on present power utilities' operation, control, protection, and reliability [31]. In other words, the increasing deployment of DG units in power distribution networks is converting these networks from passive to active. The fundamental issue is that distribution networks were not designed for such activities, hence the aforementioned challenges are exacerbated in such systems. There are several types and technologies of DGs. Figure 2 (b) displays a few of the numerous types and technologies of DGs.

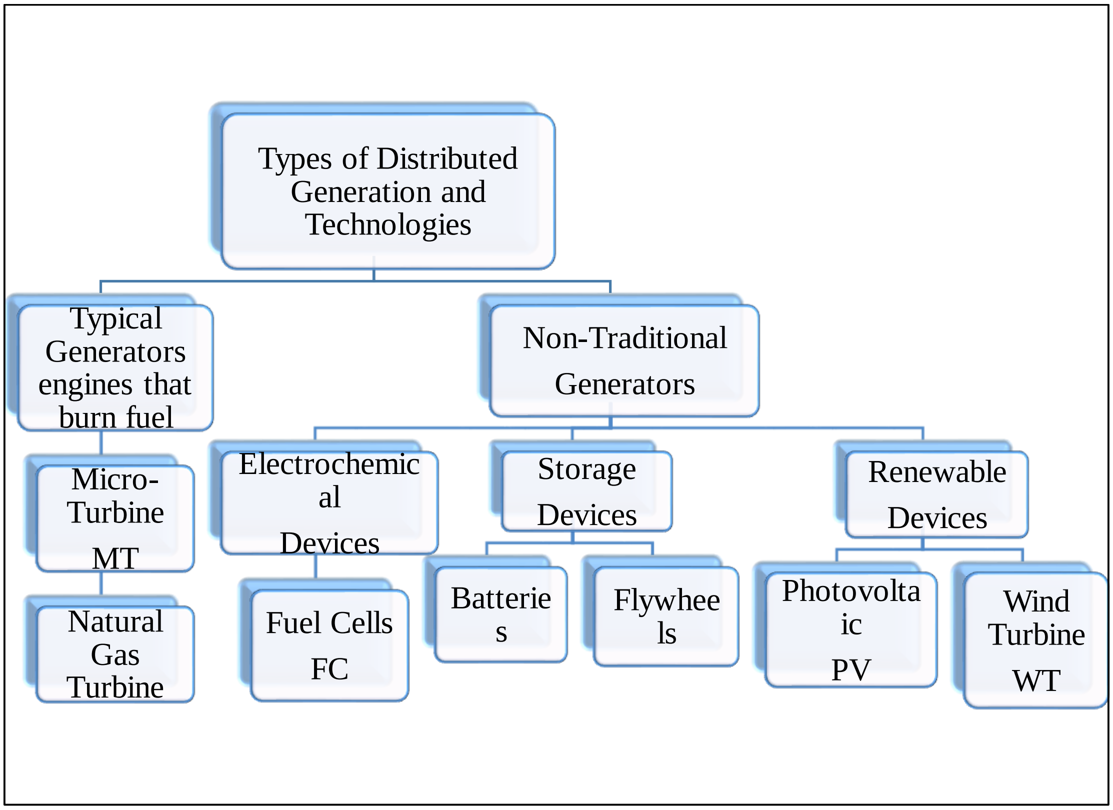


Figure.2 (b) Types and technologies of DG's

Based on the previous reasoning, it is established that introducing DG units into electrical distribution networks solves certain problems while growing their deployment causes others. When dealing with this issue, the unusual solution will be reduced to two options: the first is to completely redesign the network architecture, and the second is to introduce some sort of electrical system architecture that can operate as part of the existing network while allowing the deployment of DG units without the aforementioned drawbacks. The main option is tough to understand. The second option is introduced using the Microgrid concept. A microgrid is a modern electrical architecture that combines DG units, energy storage systems (ESSs), and loads to create a self-contained portion of an electrical distribution system where power is generated, transmitted, consumed, monitored, and managed on a regional scale. When two-way power exchange is available, microgrids can function in tandem with the utility grid, or they can run grid-independent power islands to service local loads or isolated regions. Both utilities and customers benefit from microgrids. They can provide utilities with energy or other services (such as frequency and voltage support), and they can provide customers with consistent and high-quality power. In a more futuristic perspective, the design of future power systems will resemble that of contemporary energy systems significantly, with the Microgrid projected to be the key architectural component. The smart grid concept is also introduced in these works as a structure with high energy efficiency, sustainability, and renewable energy sources as generators, reliability, security, advanced sensing, measurements, advanced control methods, load usage awareness, and advanced load components (e.g., electric vehicles), and integrated information and communication infrastructures.

The establishment of a Microgrid enables the efficient use of renewable energy sources (RESs) and energy storage technologies. Because Microgrid is installed in a specific geographic location, RESs that operate in that region can be chosen as DG units. Furthermore, in compliance with load characteristics and power regulations, ESSs are typically incorporated into Microgrid systems. Heat generating, in addition to electricity generation, is a concept that is commonly connected with Microgrid. In the future, microgrids are expected to contain both power and heat demands, as well as generators.

Finally, a Microgrid that homogenizes RESs and ESSs is a modern concept that will provide a viable solution to the future dilemma of fossil fuel scarcity, environmentally friendly electricity generation, power supply to remote areas, and power supply to critical loads that require an uninterrupted power supply.

2.1 Micro grid

A traditional power system's main feature is that the entire grid is linked together into a large grid; the most significant advantage of the centralized power grid is the ability to fully enhance the efficiency of energy use; however, the centralized power grid has some drawbacks: high costs, operational difficulties, and it is difficult to meet users' increasing requirements for safety and reliability [35]. The vulnerability of the power infrastructure has been amply demonstrated, particularly in recent years, by a series of large-area blackout disasters. As a result, people began to explore for other ways to enhance the power system's development paradigm. Following the 2003 North American blackout, experts decided that developing distributed power is far easier and faster than reforming the power infrastructure to improve security.

A microgrid is a regulated power supply system consisting of distributed power, load, energy storage devices, and control devices. It can reduce feeder loss, improve the reliability of local power supplies, and boost energy efficiency. The United States, Europe, Japan, and a number of other countries pooled their reality and suggested the notion of microgrids, as well as aggressively pursuing related research. So far, the microgrid has produced positive outcomes in theory and implementation, and it is steadily moving in an intelligent direction. It has become an important component of smart grid construction as well as an essential component of smart distribution grid construction.

The microgrid may run in a variety of modes, including: Grid-connected mode in which a microgrid acts as a backup or supplies a small fraction of the electricity. A National grid as well as a Microgrid service the supply region in such operating scenarios. This mode ensures a low-cost, reliable power source. The second operating mode is decentralized or island mode. The microgrid is the only source of electricity in the area. This permits power to be distributed to previously inaccessible areas. The decentralized form is suitable for use with renewable energy sources.

2.2 Microgrid Architecture

A microgrid is a power architecture located at the distribution level of a utility power system. A microgrid's structure consists of distributed producing sources, energy storage systems, and loads. In addition to these three components, microgrids include power electronic interfaces, control systems, and communication systems. To enable high-quality, dependable power transmission from generating and storing units to loads/grid and from the grid to loads/storage devices, power electronics interfaces are necessary. Power electronics also have a safeguard to deal with emergency/faulty circumstances. A control system manages the whole system and governs electricity transfer inside the microgrid. Because microgrid components usually operate as independent entities, a communication system is included to act as a method for information transfer between these entities or, if one exists within the system, central controllers. The point of common connection is another important component in microgrid architecture (PCC). A PCC is a controlled switch installed between the utility grid and the microgrid, allowing the microgrid to be detached or rejoined to the utility grid based on operating criteria. A schematic microgrid structure is shown in Figure.2.1.

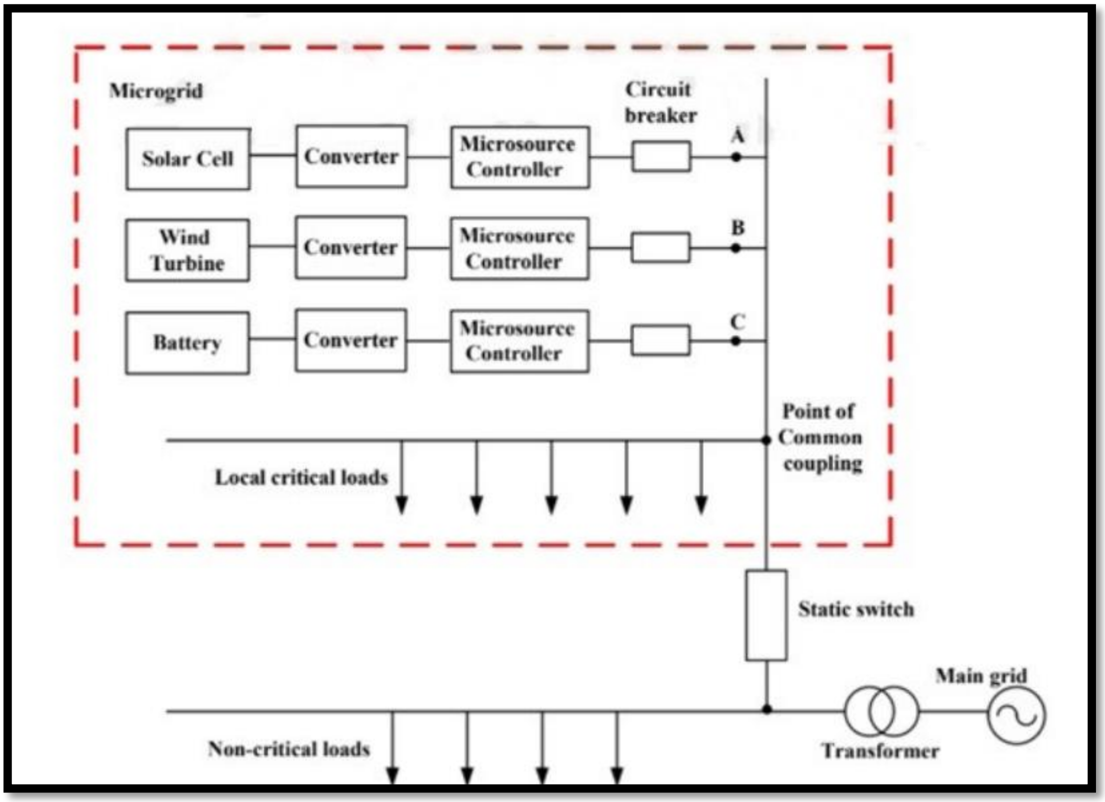


Figure.2.1 Schematic microgrid diagram [4]

Microgrids produce power from accessible energy resources using dispersed producing sources. DG sources are typically classified as renewable or nonrenewable energy sources according on the type of resources they use. Wind turbines, solar cells, fuel cells, mini-hydro turbines, wave/tidal turbines, geothermal turbines, and biomass turbines are examples of long-term and ecologically beneficial energy sources. Induction and synchronous generators driven by combustion engines that run on fossil fuel, propane, or oil are examples of nonrenewable energy sources. Energy storage systems are used to store excess energy in microgrids when load demand is less than the momentary capacity of generators, and they are also responsible for compensating for a lack of energy when the momentary capacity of generators is less than the load demand. Storage systems (ESSs) are critical components of microgrids that maintain power balance in the face of demand changes and transients. ESSs are commonly thought of as energy buffers that balance energy supply and demand. Common ESSs include batteries, flywheels, supercapacitors, and superconducting magnetic energy storage devices (SMEs).

A microgrid may be subjected to a range of loads. These loads are typically classified as critical or noncritical. Critical loads must be supplied with high-quality electricity and, more importantly, on a continuous basis (uninterrupted power supply). Non-critical loads have more flexible power quality standards and can be shaded (turned off) as necessary. Load classification in a microgrid is crucial for meeting net import/export power in grid-tie mode, regulating voltage and frequency in island mode, reducing peak load to optimize the performance of DG sources, and improving power quality and dependability of sensitive loads. A microgrid may accommodate both AC and DC loads.

Power electronics technology facilitates the connection of generators, storage devices, and loads in microgrids. These interfaces guarantee the interoperability of a broad variety of Microgrid components while also providing efficient and adaptive energy exchange. Thanks to power electronics interfaces, microgrid systems may operate in either islanded or grid-tied modes. In general, power electronics interfaces are expected to provide fixed power and local voltage generation, assist the DG unit in meeting load demand through the use of energy storage systems, incorporate control methods for load sharing between DG units, and integrate various key technologies for future power systems [32].

Another component of microgrids that is closely tied to power electronics is the control system. The major functions of the control system include management of energy export/import from and to the utility grid, regulation of active and reactive power flow within the system, control of DG sources and their characteristics, and control of system frequency and voltage within prescribed limits. Control in Microgrid Systems is an important aspect of microgrid research that addresses a wide variety of issues.

The communication system is a Microgrid component that allows critical information to be transmitted between different parts of the microgrid. A communication system is used to coordinate the controllers of DG units, ESSs, loads, and the grid in order to produce a more robust match between demand and supply of power inside the microgrid. Overall, this technique boosts energy efficiency and economic value to the microgrid operator.

2.3 Types of Microgrid

The first type of MG–island microgrid consists of DGs and DSs that provide sufficient power to small-scale users or communities. Because of its remoteness, this has been separated from the utility grid, preventing access to the main system.

The second kind, LV microgrids, meet electrical demands on a small scale, akin to a commercial farm or a rural farmhouse. It works in the same way as a grid system. As a consequence, if there are any issues with the distribution producing network or the Distribution Storage units, the customer's power requirements are satisfied inside the island mode.

In the third case, the LV micro grid provides services to a number of LV clients, and power generation is reliant on a large number of small-scale DGs such as solar panels, wind turbines, or micro turbines. Because they provide power to only a few consumption points on the one hand, and a comprehensive low-voltage network running with the assistance of either an MV or an LV transformation system on the other, LV microgrids can have a limited or wide range.

LV-Microgrid is the fourth kind of MG, which is further classified into MV-Microgrid with high production capacity. Following that, these DG units will be connected to the main HV/MV distribution network [33]. Figure.2.2 displays the circumstances stated above.

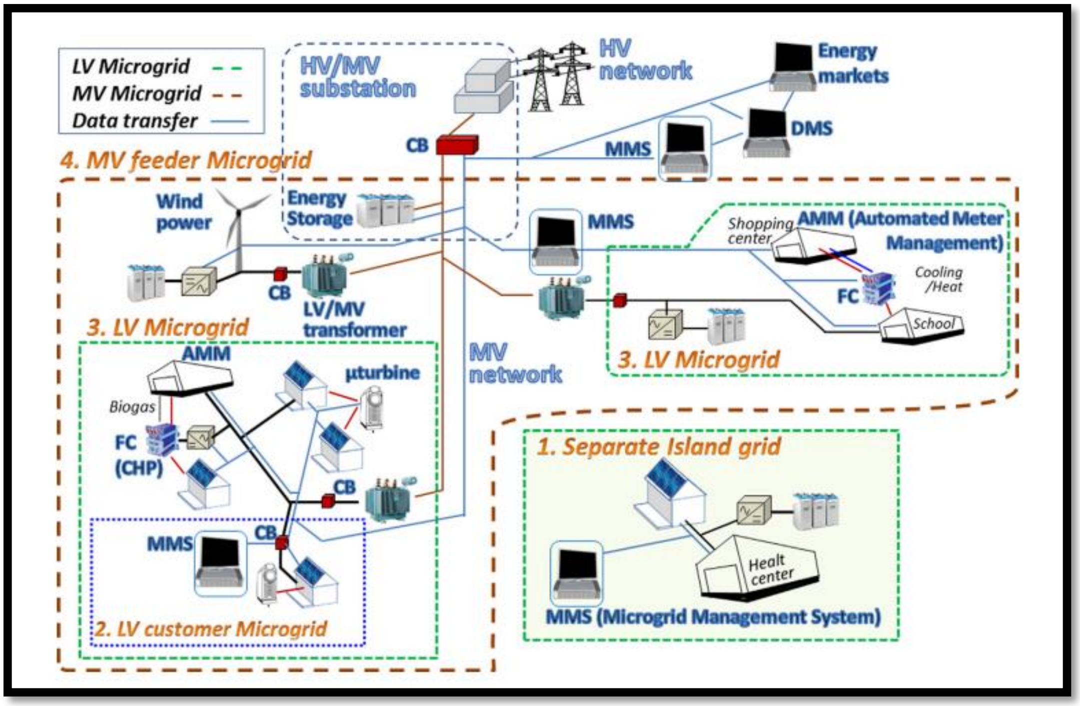


Figure.2.2 Microgrids are classified in many ways. Island microgrids, low voltage customer microgrids, low voltage microgrids, and medium voltage microgrids [33] are all examples of microgrids.

All of these microgrids show that microgrids may come in a variety of sizes. The maximum LV customer-side grid scope is 10 kW. Many DERs ranging from 10 to 100 kW are used in island and low-voltage microgrids, and their real-time installed capacity is less than 1 MW.

The increasing MG scale, i.e. the number of distributed generating and storing units, enhances balancing capacity and controllability, and hence system accuracy and stability.

The size and voltage of microgrids are connected. Consumer LV grids are connected to the LV central grid, whereas LV micros, which contain many DERs or customers, are connected to the MV-central grid [34].

Microgrid setup is achievable because to the manner electricity is transmitted and distributed through microgrids. Figure 2.3 shows high frequency (HFAC) AC MGs or DC MGs, hybrid DC/AC MGs, and line frequency AC MGs (LFAC).

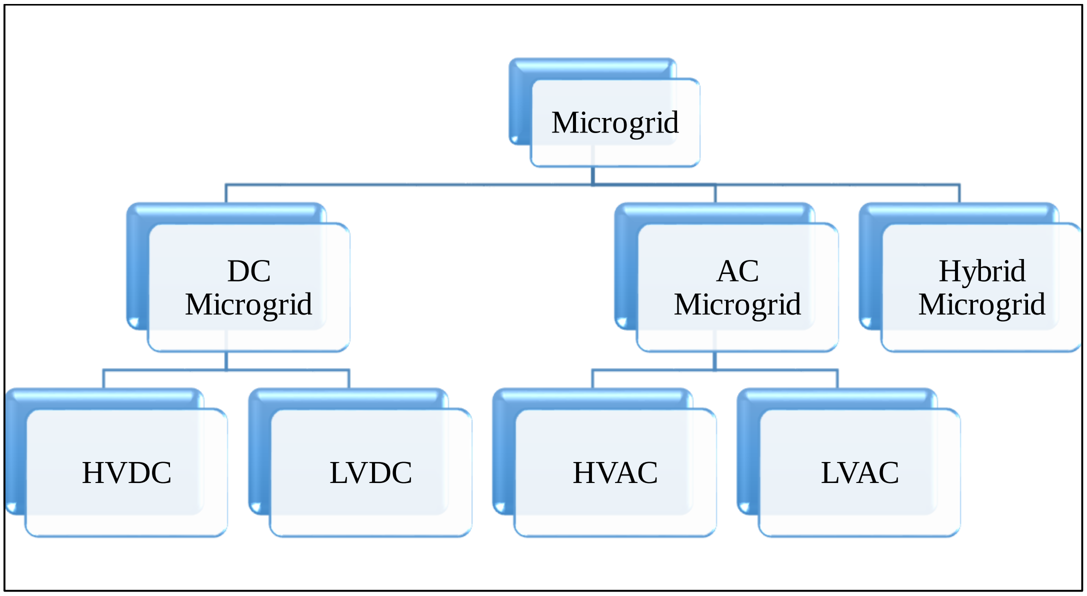


Figure. 2.3 Microgrid classification depending on electricity source.

2.3.1 AC Microgrid

In high-frequency AC microgrids, power is distributed at a frequency greater than the line frequency (50Hz/60Hz). These systems' power electronics include high-frequency transformers and appropriate converters. Figure 2.4 depicts a typical HFAC microgrid. These systems often function at multi-kHz frequencies; however, certain microgrid systems are frequently designed to operate at 500Hz [44]. In general, high-frequency power transfer has several advantages over line frequency AC and DC microgrids, including the ability to improve power quality at higher frequencies, reduce acoustic noise at frequencies above 20 kHz, use soft switching to reduce power losses, and make power transformers and passive filter elements smaller in value and size. The basic disadvantage of HFAC, on the other hand, is that they are limited to small areas since the losses rise significantly with distance.

DG units that generate grid-compatible AC power are usually connected directly to the AC distribution network, however DG units that generate variable AC power require connect to the distribution network via an additional AC/DC/AC or AC/AC converter. DC/AC converters link DG units that produce DC power, whereas bidirectional DC/AC-AC/DC converters connect storage units. AC loads are fed directly from the distribution network, whereas DC loads must be powered via an AC/DC converter.

The control, protection, installation, and operation of LFAC microgrids with renewable and non-renewable DG units have been extensively investigated in the literature. The simplicity of AC microgrids arises from an understanding of AC distribution networks. The vast majority of operational loads on the market are designed to be powered by alternating current (AC). AC microgrids, unlike DC microgrids, do not require a central inverter, making this construction more flexible and resistant to failure. AC microgrids are less efficient than DC microgrids and need synchronization, which increases system complexity.

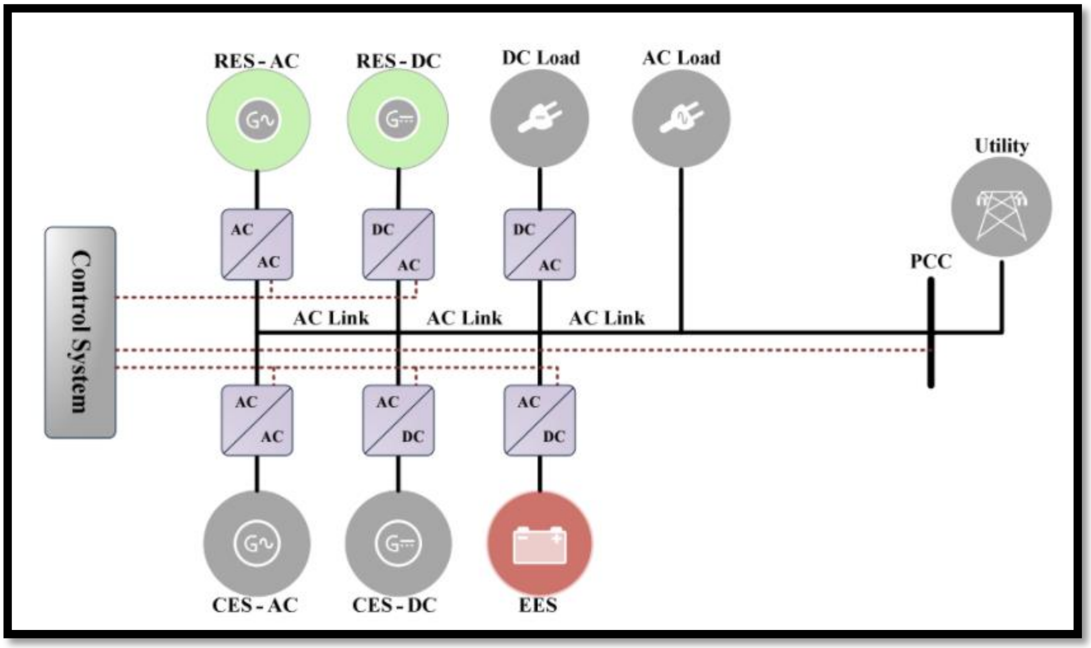


Figure 2.4 AC Microgrid [44]

2.3.2 DC Microgrid

The bulk of modern loads found in homes, offices, and commercial buildings are direct current (DC) loads (PCs, printers/scanners, TVs, various domestic appliances, and so on). The amount of pure AC loads in present systems has decreased considerably as a result of advancements in power electronics and control theory. Even ordinary alternating current motor loads (washing machines, refrigerators, air conditioners, etc.) are being replaced with inverter-equipped alternating current motors. DC power is utilized to control motor speed and reduce overall energy consumption. Despite the fact that many DC loads are in operation, they are all powered by AC power according to the AC power distribution system standard. To accommodate the shift in power characteristics, AC/DC converters are fitted at the corresponding power inputs. These converters are often built with large line transformers and passive electronic components, which results in poor power conversion and undesirable power system dynamics. As a solution to these issues, a direct current (DC) power distribution system was developed and used in a variety of systems such as communications networks, ship power systems, and electrical vehicles, where it proved to be more efficient and cost-effective than alternating current (AC) distribution systems. DC distribution systems can be used in microgrids with DC loads, DC sources, and DC storage units.

A low voltage DC (LVDC) distribution network has been proposed to overcome the aforementioned challenges and better understand future power systems based on DC microgrids [45]. The authors of [46] show how an LVDC distribution network may improve power delivery efficiency, provide higher power quality than a standard AC distribution network, and allow for DG unit connection. The advantages and disadvantages of DC distribution system research for industrial power systems are investigated. The authors depict the interaction between power converters and grounding issues in DC power distribution systems. The sustainability of a DC distribution network is thoroughly investigated in the context of DC microgrid applications to small-scale residential buildings and the interface of renewable energy resources [47]. When compared to AC microgrids, microgrids based on DC distribution networks provide benefits such as simple construction, low system costs, and overall improved efficiency (fewer converters) [45,46].

A common DC microgrid arrangement. Figure 2.5 displays this configuration. DC generating and storage units are connected to the DC link via a DC/DC converter, AC generation units are connected to the DC link by AC/DC converters, and local DC loads are supplied directly or via an additional DC/DC converter from the DC link. A DC/AC converter connects pure AC loads. The DC microgrid's connectivity to the utility grid is completed by a central DC/AC converter. At the DC distribution level, synchronization of source and storage outputs is not required. The benefit of the system minimizes the system's complexity. [48] covers several types of DC microgrids, including three DC link configurations: monopolar, bipolar, and homopolar.

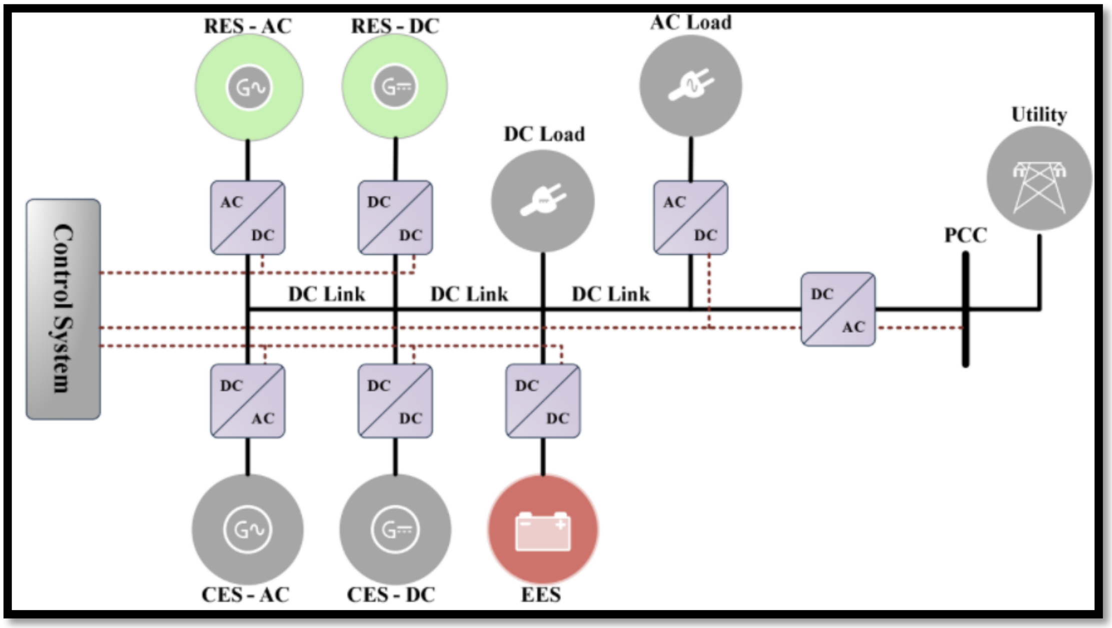


Figure 2.5 DC microgrid [45]

2.3.3 Hybrid Microgrid

The necessity to integrate the benefits of both AC and DC microgrids led to the development of hybrid AC/DC microgrid architecture. In hybrid microgrids, DC sources are integrated with DC loads and energy storage units, whereas AC sources are connected with AC loads. Hybrid design is a persuasive method of integrating several DG units into the present electric system. Power converters are used in these systems to electrically and controllably separate the microgrid's AC and DC components. AC-generating DG units are positioned on the AC side of the microgrid with AC loads, whereas DC-generating DG units are located on the DC side of the microgrid with storage.

The primary benefits of hybrid microgrids are as follows [49]: less unnecessary multi-conversion steps, leading in reduced total power loss The removal of integrated AC/DC converters for DC loads simplifies and decreases costs. The connection of all DC loads to the hybrid microgrid's DC side simplifies the management of harmonic injections into the AC side via the central DC/AC converter, ensuring high-quality AC power in the utility grid; the DC grid is capable of solving negative and none (almost zero) sequence current problems caused by unbalanced loads in the AC distribution network, eliminating the need for neutral wire in transmission, resulting in a significant reduction in related costs. A hybrid microgrid is depicted in Figure 2.6.

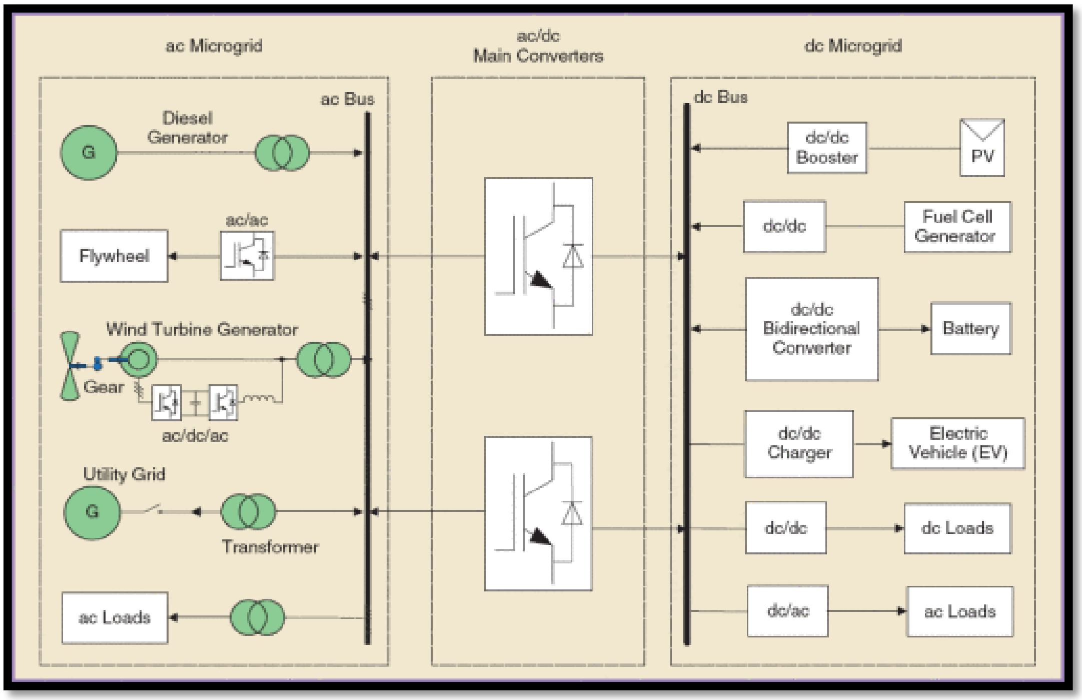


Figure 2.6 Hybrid AC/DC Microgrid [49]

2.4 Modes of Operation

MGs function as in:

- Island mode, if MG operates autonomously;
- Grid-connected mode, if MG is connected to the main grid.

The usefulness of microgrids, the availability of essential energy sources, and the cost of those sources all impact local power generating options on the island. Consider the limitations of MV or LV transformers, as well as low voltage network congestions. Microgrid rapidly changes to a self-sufficient islanding operation in the case of an MV or HV system failure. A seamless transition from networked to islanding generation is crucial for assuring continuous power supply.

When MGs are linked to the grid, the extra power generated in the MG may be transmitted to the main grid, offering supplemental services. The radial-type MG is connected to the common connection point through static switches.

PCCs are primary transformers that separate the power grid from the MGs. Each feeder has circuit breakers and micro source controllers. Local critical loads are transferred to local generating resources, whereas non-critical loads do not have local generation. During disturbances or maintenance, the static switch aids in isolating the MG.

2.5 Büyükada and designing a Micro grid (Case Study)

Büyükada (also known as Prince's Island) is one of the nine Islands (the largest) in the Sea of Marmara near Istanbul. It is a tourist attraction spot, especially during the summer season. 5.46 km2 island [36] has both historical and natural spots. Electricity on the island is as important as in any other place. The island's energy need is fulfilled by the electricity transmission from Anatolian Istanbul. The island itself has a great potential for renewable energy accompanied by the Microgrid. On average the land receives 7 hours-7.5 hours of the sun which makes it favorable for the Solar Energy System (Photovoltaic Panels) and an average of $6.87ms^{-1}$ of wind which favors a medium-size Wind Turbine. Trash collected from the island can also support the Biomass energy. This study uses only solar and wind as energy sources.

2.5.1 Current Energy Distribution Approach

Currently, Büyükada and all other Islands are provided with electrical energy from the Asian part of Istanbul. Starting from Bostanci till Kartal there are a total of 8-9 substations Figure 2.8 medium voltage 10.5kV is transmitted from the source under the sea. After small line losses, approximately 10.2kV-10.3kV reaches the Büyükada.

Büyükada and the other islands are connected in the ring topology manner assuring the uninterrupted electric supply. A network of 23 distribution stations spread across 6 islands is responsible for all the supply needs. Pad-mounted transformers with SCADA step down the voltage level to 230V (single-phase) or 400V (three-phase) for local distribution and utilization. Total electrical consumption is measured in kWh (Kilowatt-hour). The total installed capacity of Adalar is 45.23 MWe with a peak load of about 20.30MWe (ref; AYEDAŞ, 2020). Figure.2.7 demonstrates the idea of ring topology and the electricity distribution where red lines are the ring topology wires for supplying electricity and the numeral indicates the no. of substations on each island.

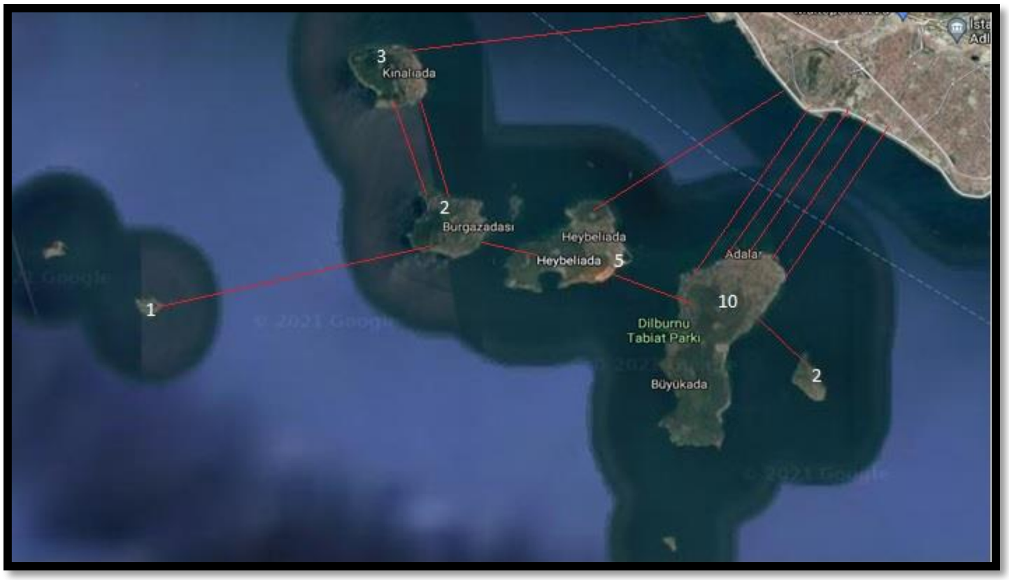


Figure.2.7 No. of distribution station on the Islands (white) and ring topology network (red lines)

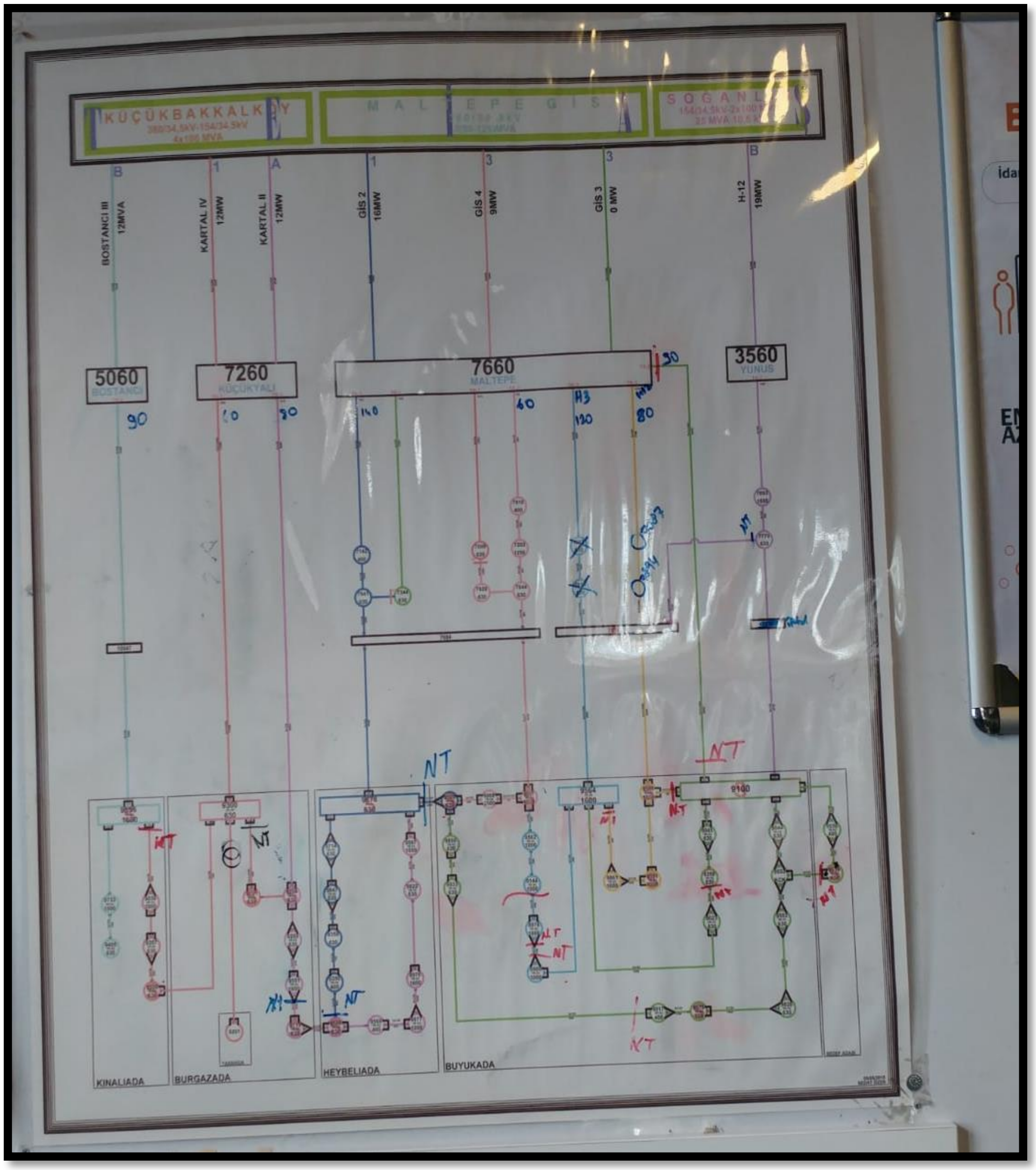


Figure 2.8 Transmission line diagram (From Asian Istanbul to Islands)

2.6 Solar Data

Büyükada has an average sunshine duration of about 7.5 hours [26]. Roof-mounted solar panels with MPPT (Maximum Power Point Tracking) can produce green energy which not only is used for the island itself but can also be transmitted to other islands. The amount of energy a solar panel produces depends upon Peak sun hours. Even with 7.5 hours of Sun peak hours can only be 4 hours-5 hours. Solar radiation peaks at solar noon, when the sun reaches the highest point in the sky [37].

The amount of solar radiation and the energy produced is also location and meteorological-dependent. Before the installation of PV panels, all of those factors need to be calculated. For any given location the peak sun hours is the number of hours per day during which the average solar irradiance is 1000 watts per square meter (W/m^2) or 1 kilowatt per square meter (kW/m2) at the site. The max. solar hours can only be 2-3 hours for the given panel at a given point. For example:

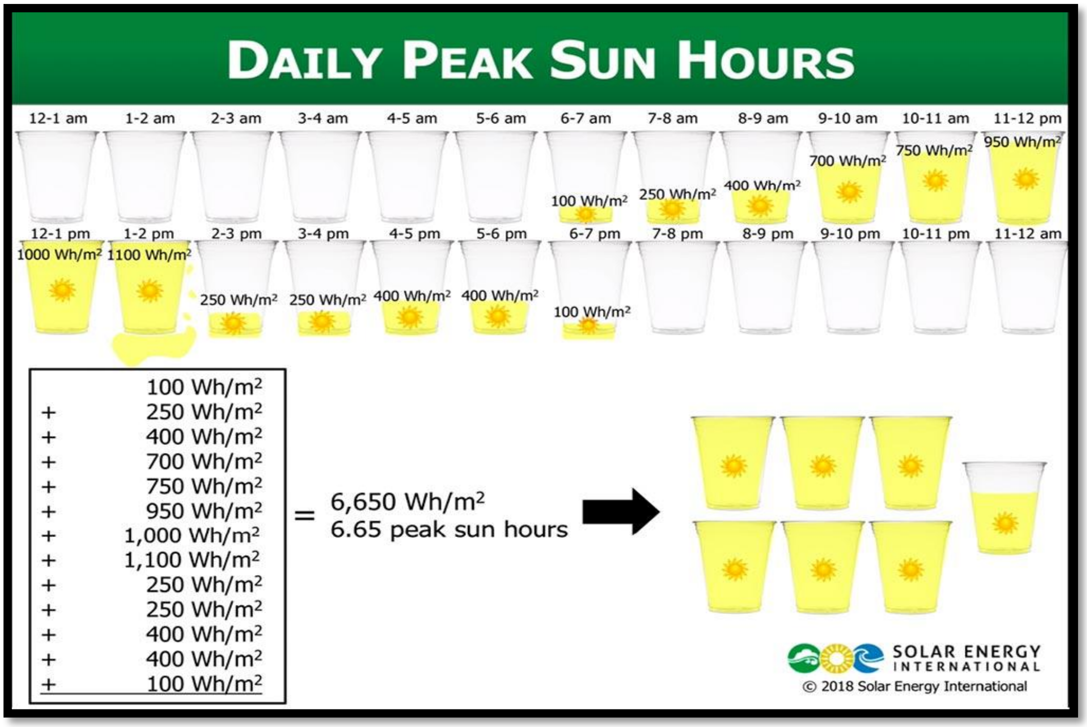


Figure 2.9 (a): The daily Peak Sun hours value is calculated by adding together the solar irradiation throughout the day. Solar Energy International [38] is the source of the image.

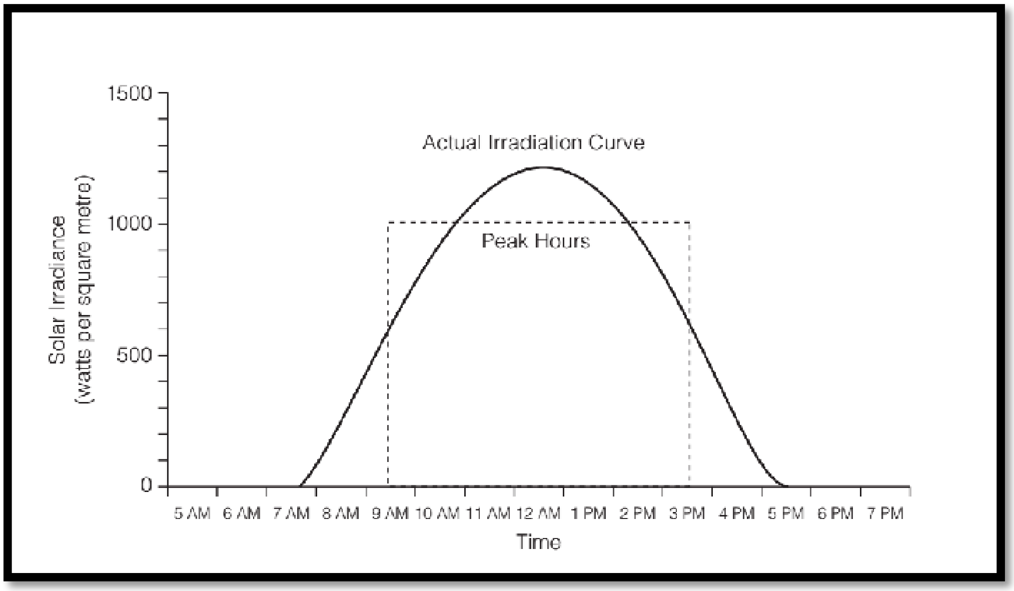
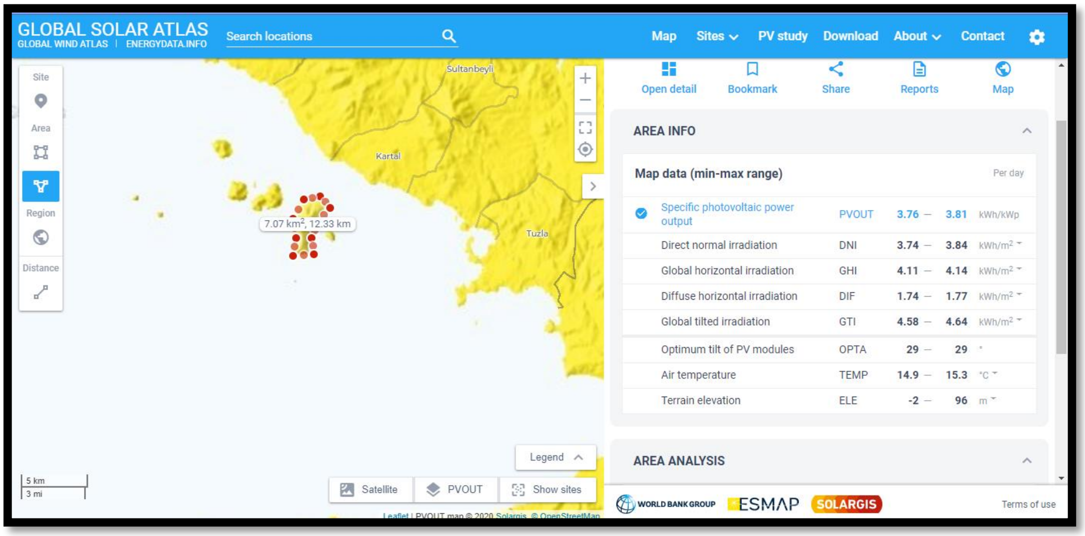


Figure 2.9 (b): Solar Irradiance vs Time graphically

As mentioned before Büyükada has an average of 7.5 hours of sunlight. Using the data from the "global solar atlas" shows that a PV panel with a tilt of 29 degrees will produce a min. of 3.76kwh per day.



AREA INFO

Map data (min-max range)				Per day
Specific photovoltaic power output	PVOUT	3.76 —	3.81	kWh/kWp
Direct normal irradiation	DNI	3.74 —	3.84	kWh/m²
Global horizontal irradiation	GHI	4.11 —	4.14	kWh/m²
Diffuse horizontal irradiation	DIF	1.74 —	1.77	kWh/m²
Global tilted irradiation	GTI	4.58 —	4.64	kWh/m²
Optimum tilt of PV modules	OPTA	29 —	29	°
Air temperature	TEMP	14.9 —	15.3	°C
Terrain elevation	ELE	-2 —	96	m

Figure 2.10 Average solar parameters using “Solar Global Atlas” for Büyükada.

Simulation software HOMER Pro (explained in chapter 4) is also a data extraction software that plotted a graphical "Global Solar Time Series" between hours (h) as a horizontal plot and global solar (kW/m^2) as a vertical plot throughout the year for a selected site Figure. 2.11 whereas Figure. 2.12 shows the average monthly global plot.

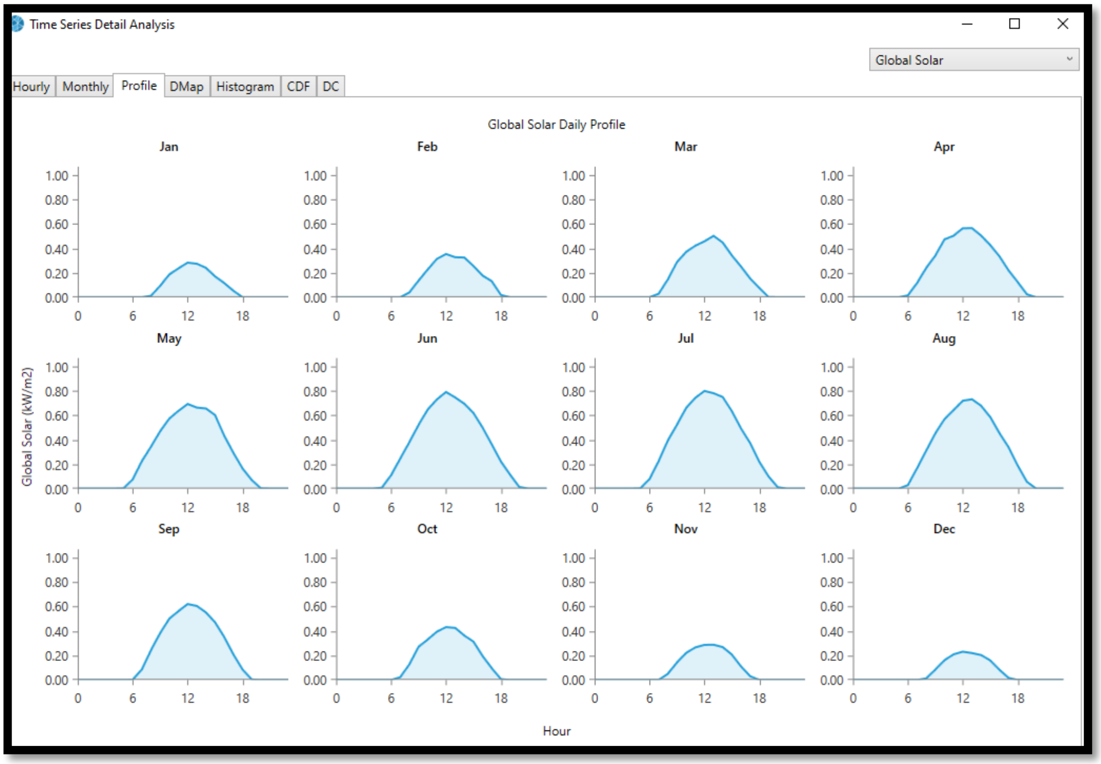


Figure. 2.11 Global Solar profile. Hours (h) vs Global Solar (kW/m^2)

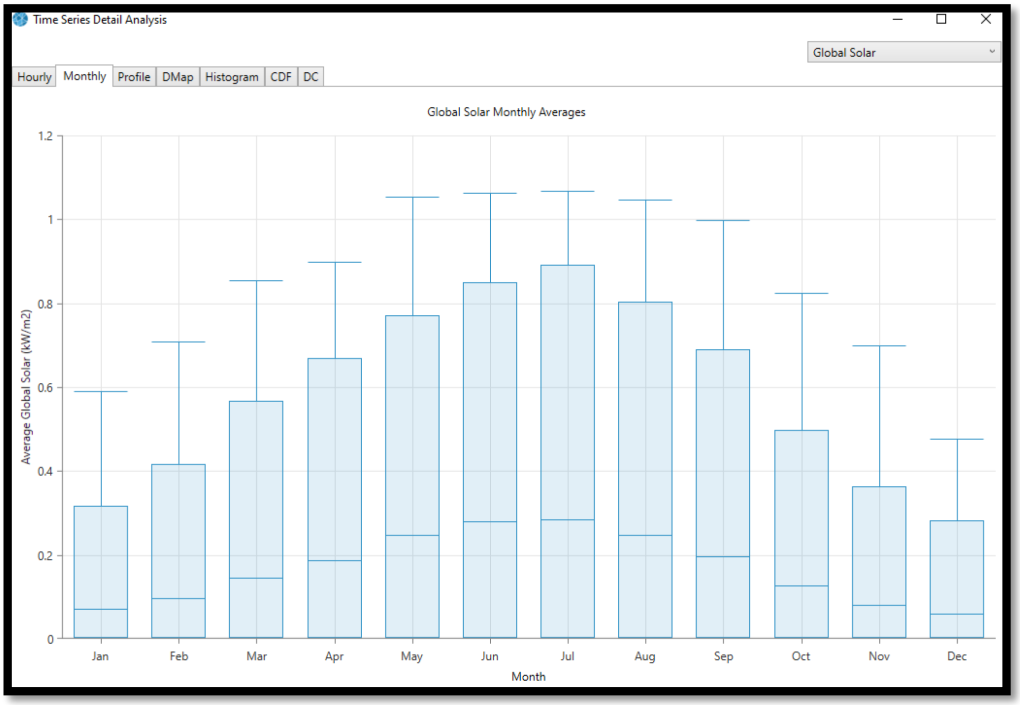


Figure. 2.12 Global Solar Monthly Average. Month vs Average Global Solar (kW/m^2)

2.7 Wind data

The general structure of the Wind Energy Conversion (WEC) system is depicted in Figure 2.13. Wind turbines are used in wind energy conversion systems to transform the kinetic energy of the wind into mechanical energy. A wind turbine may be built in a number of different configurations, the most common of which being a horizontal wind turbine with three blades. A wind turbine used for energy generation, regardless of its mechanical design, is usually connected to an electrical generator. The designer often selects the generator class based on efficiency, integration complexity, and cost.

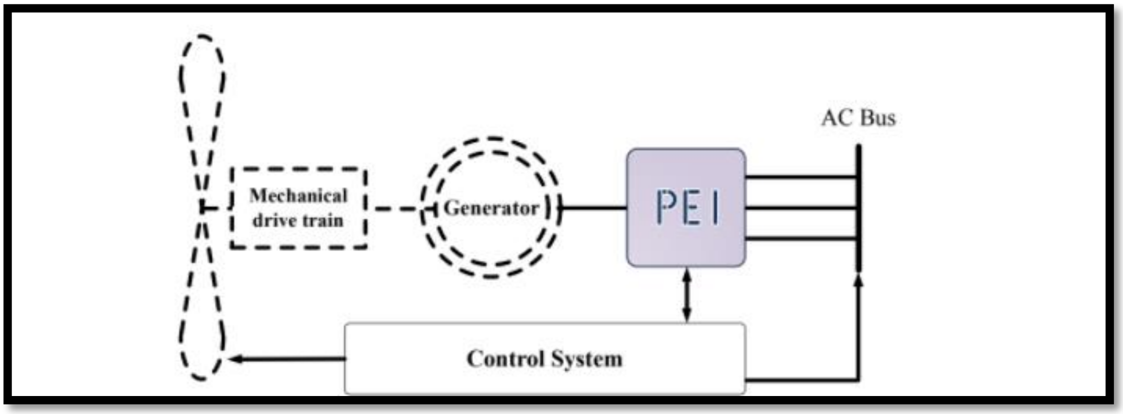
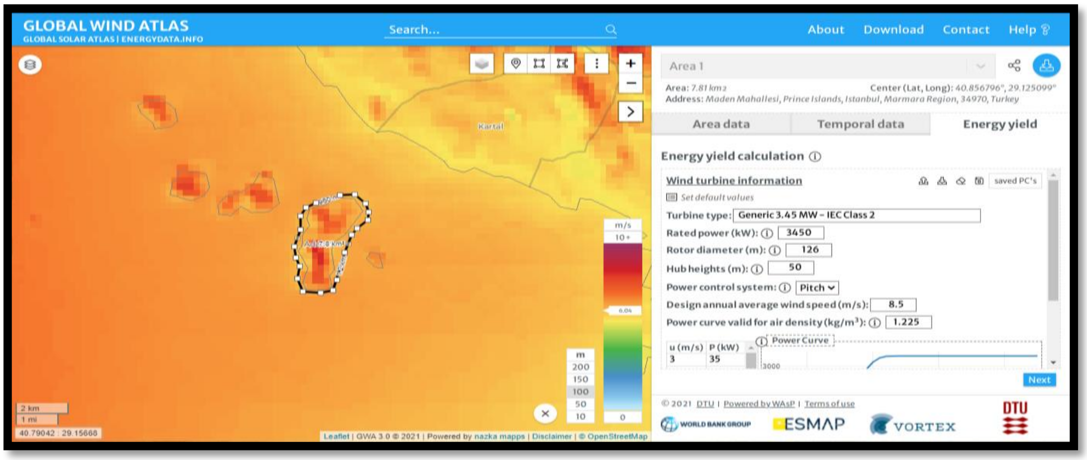


Figure. 2.13 General structure of the WEC system

Today's wind turbines range in size from a few kW to two megawatts. Variable-speed wind turbine generators can include permanent magnet synchronous generators (PMSG), electrically excited synchronous generators (EESG), induction generators (IG), and doubly-fed induction generators (DFIG), all of which are electronically coupled to Microgrid via power electronics converters.

The average wind speed was calculated using the wind atlas. The average wind speed in Büyükada and the Marmara Region is 8.5m/s. Figure.2.14 depicts the wind density and potential wind turbines.



Area 1

Area: 7.81 km2

Center (Lat, Long): 40.856796°, 29.125099°

Address: Maden Mahallesi, Prince Islands, Istanbul, Marmara Region, 34970, Turkey

Energy yield calculation

Turbine type: Generic 3.45 MW - IEC Class 2

Rated power (kW): 3450

Rotor diameter (m): 126

Hub heights (m): 50

Power control system: Pitch

Design annual average wind speed (m/s): 8.5

Power curve valid for air density (kg/m³): 1.225

u (m/s)	P (kW)
3	35

Figure. 2.14 Wind data for Büyükada

Congeneric to solar profile wind time series is also extracted from HOMER. Both solar and wind time series are vital for renewable energy production forecast and to improve the uncertainty complexity of renewable energy. Figure. 2.15 is the hourly wind speed profile whereas Figure. 2.16 is the monthly average wind speed.

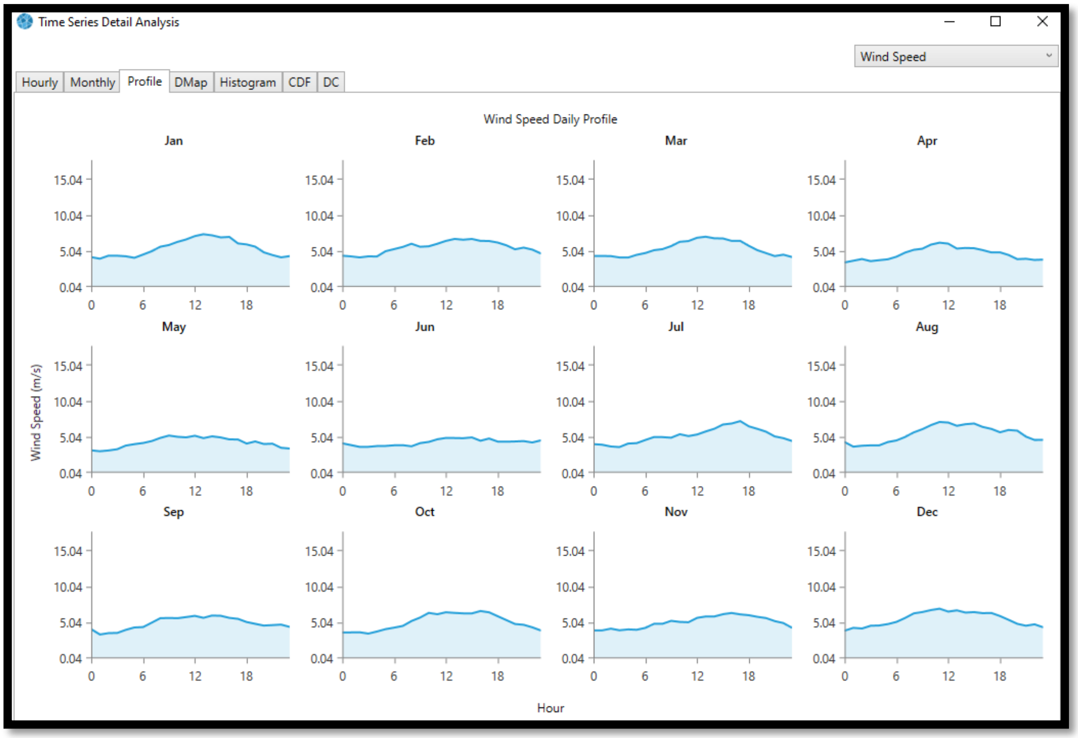


Figure. 2.15 Wind Speed Daily Profile. Hours (h) vs Wind Speed (m/s)

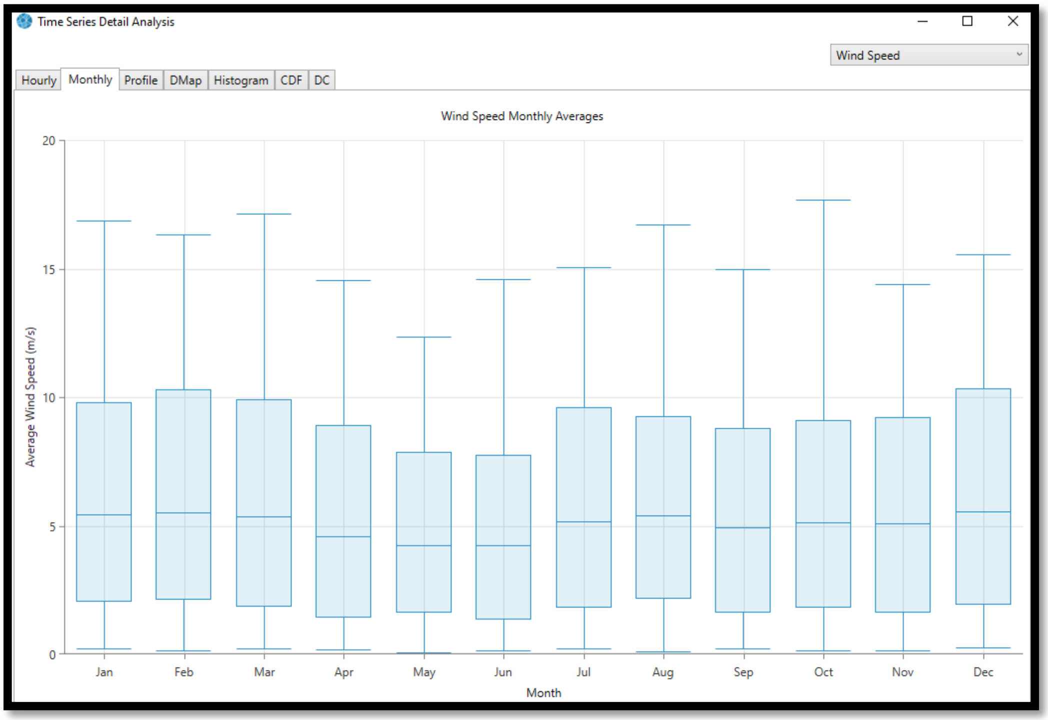


Figure. 2.16 Wind Speed Average Monthly. Month vs Wind Speed

2.8 Limitations

Since Büyükada is a historical place renovation, construction and reservation are very strict. Three major governing bodies named KUDEP, the fifth protection board, and the ministry of heritage are responsible for decision-making. Above mentioned bodies are in hieratical order from low to high. For example, if a resident intends to paint a wall or any renovation of the place they need permission from KUDEP.

3. MICROGRID CONTROL

3.1 Challenges of microgrid controls

In the near future, microgrid deployments and integration with LV distribution networks will become considerably more common. As a result, distribution systems will differ from today's traditional distribution systems. As the number of microgrids grows, the disparity will become more evident. As a result, to prevent this mismatch, proper control measures must be devised.

Microgrid controls seek to increase overall efficiency by optimizing heat, gas, and electricity generation, as well as electrical system operation. Furthermore, given the likelihood of competing requirements and limited communication, managing a diverse set of micro sources would be exceedingly challenging. Control action is obviously tough with potentially lost input parameters in the event of decentralized or centralized controllers.

Due to the "plug-and-play" nature of MGs, moving between islanded and grid-connected modes may result in frequency and voltage mismatch control concerns. When numerous micro sources are connected and unplugged at the same time, the previously mentioned property may pose significant problems [89].

3.2 Control Strategies

The MG system management and control includes power flow regulation, control over power electronic devices, energy resource management, and power quality. The primary distinction between MGs and traditional grids is their cutting-edge control approach for controlling network-connected devices. Because microgrids are dispersed, it is a vital technique for successful power generation and management [50]. To maintain a consistent and constant power supply, the DG units display intermittent behavior that must be regulated suitably utilizing ESS units. Furthermore, MGs must be properly controlled while operating in an isolated mode to ensure a smooth transition between operational modes that provide stable frequency and voltage; thus, MG control strategies are difficult because extensive research is required to identify the most viable solution based on the requirements. The following are the typical main control goals in the MG environment [48, 51, 52]:

- **Protection:** This comprises energy flow monitoring, important device testing, and grid fault management.
- **Stability:** It regulates voltage and frequency when operating the MGs in a variety of settings. It ensures dependable and stable power networks in both AC and DC MGs.
- **Power balance:** It is concerned with the synchronization of DG supply and optimum load-sharing.
- **Electricity transmission** denotes the interchange of power between the grid and the MGs.
- **Security:** This includes energy flow monitoring, critical device testing, and grid fault management.
- **Stability:** It adjusts voltage and frequency when the MGs are used in various conditions. It enhances the reliability and stability of power networks in both AC and DC MGs.
- **Power balance:** It is concerned with DG supply synchronization and optimal load-sharing.
- **Electricity transmission** refers to the transfer of electricity from the grid to the MGs.

3.3 Control Architecture

In contrast to ordinary distribution networks, such topologies yield advanced control architecture. A typical power system does not regulate or manage power generation and storage equipment. Control techniques are difficult to describe or categorize since they rely on MG features, but most scholars investigated control strategies because it is vital to understand their qualities, which are based on hierarchical structures [51, 52, 53]. The following MG control levels have been identified in the literature using this technique:

1. Primary control

2. Secondary

3. Tertiary.

Each level differently controls the MG functions; so, we have mentioned their main functions in Figure 3.1.

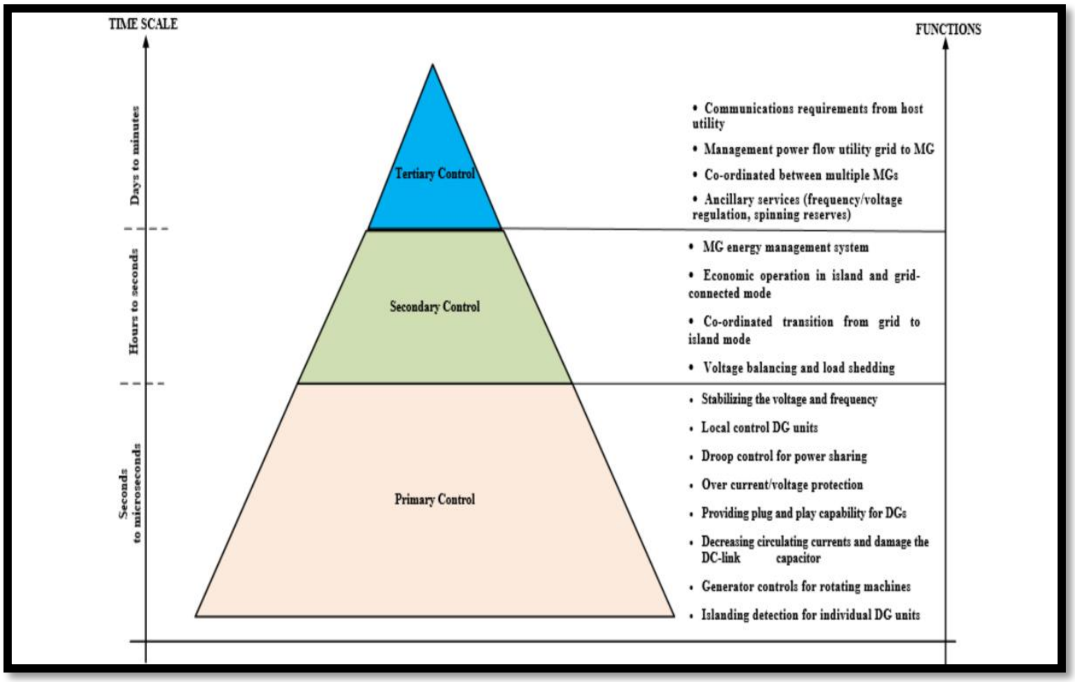


Figure 3.1. MG control architecture and primary functions [51-53]

The study work [51,53-55] depicted in Figure 3.2 addresses germane control mechanisms on the hierarchical level. The categories were made based on accessible research findings, and their characteristics are shown below, along with their links:

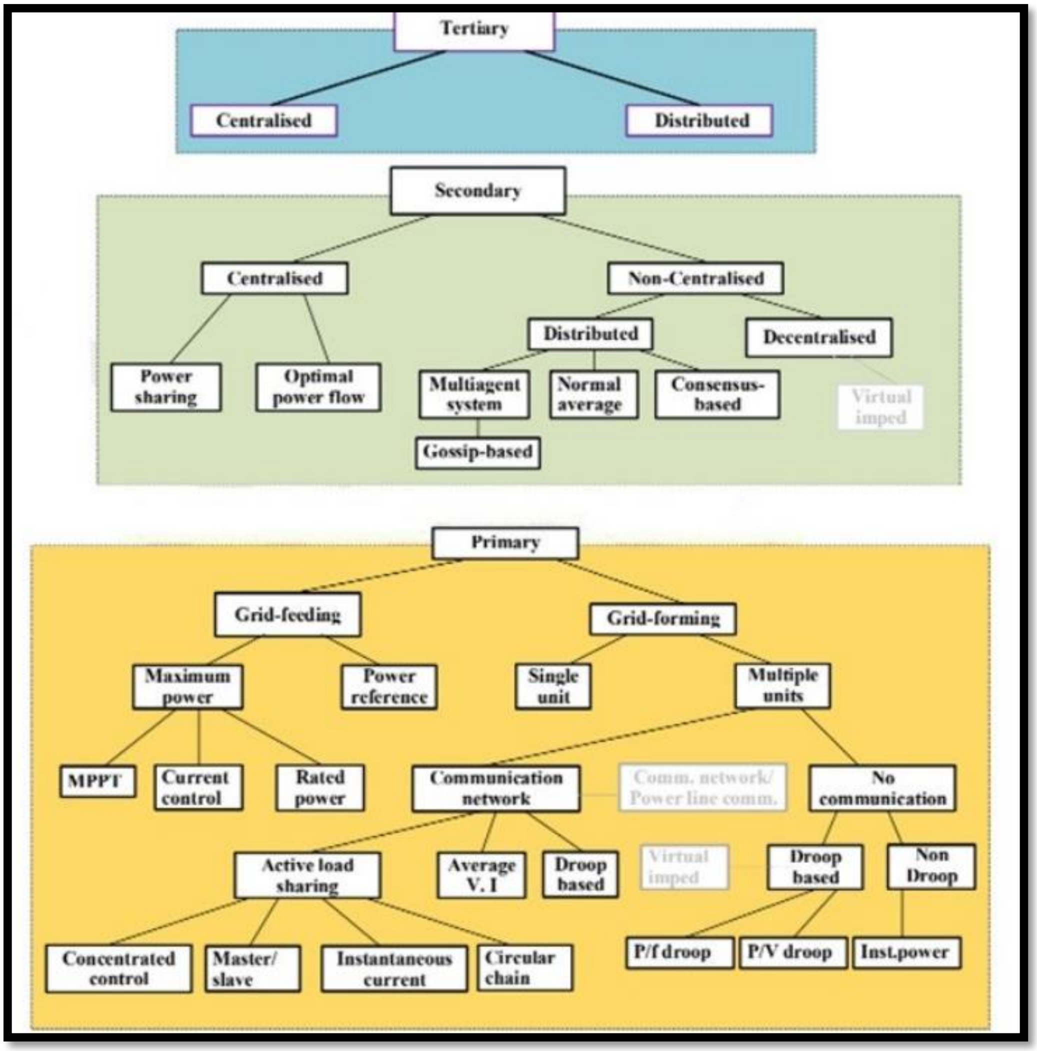


Figure 3.2. [53-55] Classification of MG control techniques

3.3.1. Primary control

The primary control level is the lowest in the control hierarchy and is used by all DGs. The primary difference between this level and others is a lack of communication. The primary control's primary role, according to the literature, is as follows [56]:

- Voltage and frequency stabilization: After switching to island mode, MG may have an unbalanced frequency and voltage owing to a mismatch between power generation and consumption.
- DG units with local control
- Power-sharing droop control
- Overcurrent/voltage protection
- DG plug-and-play capabilities
- Reducing circulating current and DC-link capacitor deterioration
- Generator controls for rotating equipment
- Islanding detection for certain DG units

Depending on their role, the literature generally recognizes two degrees of main control [54]:

i. Grid-feeding controls
ii. Grid-forming controls.

i. Grid-feeding Controls

Because the frequency and voltage of the MGs might impact the utility grid while operating in grid-connected mode, the local RES system controllers normally work in a current-control mode to harvest the maximum power from energy resources in a solar system or wind turbine [57]. Furthermore, these controls may work in an unfavorable place within the maximum power range. This mode is generally utilized to maximize power-sharing network mechanisms, which are used equally in AC and DC units but synchronize differently in AC-based systems [58]. Grid voltage filtering, zero crossing, and phase-locked loops are examples of control techniques for grid-feeding DG systems (PLL).

The authors of [54] recognized popular grid-feeding strategies such as stationary reference frame (αβ), synchronous reference frame (DQ), and natural frame (ABC).

ii. Grid-forming Control

Grid-forming control approaches are done by voltage control while the MG is in autonomous (islanded) mode, and at least one converter must be functioning to give a voltage reference [59]. The DG units require network voltage control while the MG is in grid-forming mode. In this context, two combinations have been found [60]:

Single grid-forming: This type of grid formation shows how an interface converter connected to DG units operates in grid-forming mode while simultaneously connected to supply a certain frequency and voltage. The remaining devices linked to this network absorb the greatest power through energy resources when in grid-following mode [60].

Several grid formations: When many converters are operated in grid-forming mode, a synchronization mechanism is required to provide frequency and voltage stability for AC and DC MGs, resulting in a balanced power-sharing process. According to studies, this strategy is visible and is dependent on the interface converter connections [61,62]. [61] Displays comparable architecture. The research examines grid-forming control systems that employ a variety of DG converters in depth. Figure 3.2 shows how many primary control units can work in a grid-forming environment:

a. With communication link;
b. Without any communication link.

a. Control Methods with Communication Link

This is an active load sharing approach, in which converters are configured in concurrently. Higher bandwidth control and communication lines are required, but the result is good power quality with little current sharing. Concentrated, master-slave, circular chain control, and average load sharing approaches may be utilized to determine the reference point of the current or active/reactive power; hence, active load sharing can be accomplished in the following ways [61]:

- Complete command

- Master/slave • Real-time current sharing

- Circular chain methods

The concentrated control strategy addresses both reactive and active powers via a centralized controller. The creation of a communication link between the units and the central control is required for such applications. The concentrated technique has so far been available in two flavors: central limit control and power deviation.

When dealing with central limit control, a voltage controller provides reference voltage, whilst a controller calculates the reference value of current for other units. This figure is influenced by load changes as well as total units. This method guarantees high power quality and allows for power management even during fluctuations. This method has the disadvantage of requiring a high-bandwidth communication link [54,60].

The master-slave control causes the master converter to work as a VSC (Voltage Source Converter) to regulate the voltage output, while the slave converters function as independent current-source converters, following the current pattern of the master converter. A master unit might be either centralized or decentralized. The grid takes over if just one central controller is engaged in this technique's grid-connected operational mode.

The instantaneous current sharing approach implies average current sharing without the need for a master unit. Each module calculates the voltage and current levels individually, but not the load current, utilizing voltage-reference synchronization and a common current-sharing interface.

The circular chain control works on the current-sharing concept, and the current and voltage (reference values) are computed by calculating the peak value of phase angle and voltage amplitude; hence, this method is known as the "peak-value current-sharing technique." A voltage-based control converter gets the reference value while in islanded mode, whereas the other converters simply use a current-control loop [63].

b. Control Methods without Communication Link

Droop control is used in a main control technique with no communication link [51]. These controls are dependable and inexpensive when compared to other communication techniques [64]. The strategy has shown to be profitable in the previous decade since it offers significant advantages over other alternatives such as power-sharing and plug and play, with very few flaws.

Droop-control is suitable in MV and HV networks due to the existence of a synchronous generator. In both MGs with converters and those with synchronous generators, "inertia" is critical. Low inertia in microgrids indicates online active and reactive power characteristics [53,61].

Droop control modulates voltage, frequency, and amplitudes based on reactive and active demand for inter-device power sharing. It is a typical method of distributing the power generated by synchronous generators in a utility grid. In grid-connected or islanded modes, ESS units in MGs are frequently capable of executing optimal current-sharing. Furthermore, due to the optimal power-sharing point, it has restricted integration with DG systems, which is frequently constrained to the islanded mode.

The droop technique, in contrast to the active load-sharing methodology, is used without a communication link, making it reliable. The classic droop method has the following drawbacks [65]:

Each droop attribute is controlled by a distinct variable. In such a circumstance, it is difficult to achieve more than one control aim.

- The usual droop method has been enhanced by taking into consideration the high inductive impedance between the AC bus and the voltage-controlled voltage source inverter (VCVSI). Because of resistance in low-voltage transmission lines, this assumption is still verified in MG applications.

- Because voltage, unlike frequency, is not a global variable for MGs, reactive power management may have a negative influence on the voltage regulation's critical loads.

- In the presence of non-linear loads, traditional droop techniques are incapable of determining the load's current harmonics from its circulating current. Furthermore, current harmonics impair the DG output voltage. Total harmonic distortion is a variation on the standard droop method for removing output issues (THD).

- As noted in [51], standard droop techniques have both advantages and disadvantages for AC MGs. The method's findings are as follows:

- It is necessary to identify the system in order to plot the line parameters of various approaches, such as virtual frame transformation methods and adaptive voltage droop.

- Other than LV MGs, droop techniques separate active and reactive power control.

- The sole voltage control capabilities is adaptive voltage droop and customizable load sharing techniques.

- Nonlinear loads should be accepted using broader control approaches such as virtual impedance. Harmonics in MGs are blunted by other approaches like as signal injection and non-linear load sharing.

3.3.2 Secondary Control

This level covers frequency and voltage changes in the MGs' networks (DC side of MGs). A secondary control regulates the difference between load and MG generation. The specified frequency/voltage reference and the measured values do not agree. When the secondary control is operating in the islanded mode, it is a large hierarchical control; thus, when the operational mode switches from islanded to grid-connected, extra features such as resynchronization or black-start management are required on this level. Figure 3.3 depicts the principles of the microgrid's secondary control level. Secondary control has a slower dynamic response to perturbations as compared to primary control [51].

Secondary control techniques might be centralized or decentralized [67,68]. Depending on the condition and architecture of the MG, the control levels encompass varying levels of responsibility.

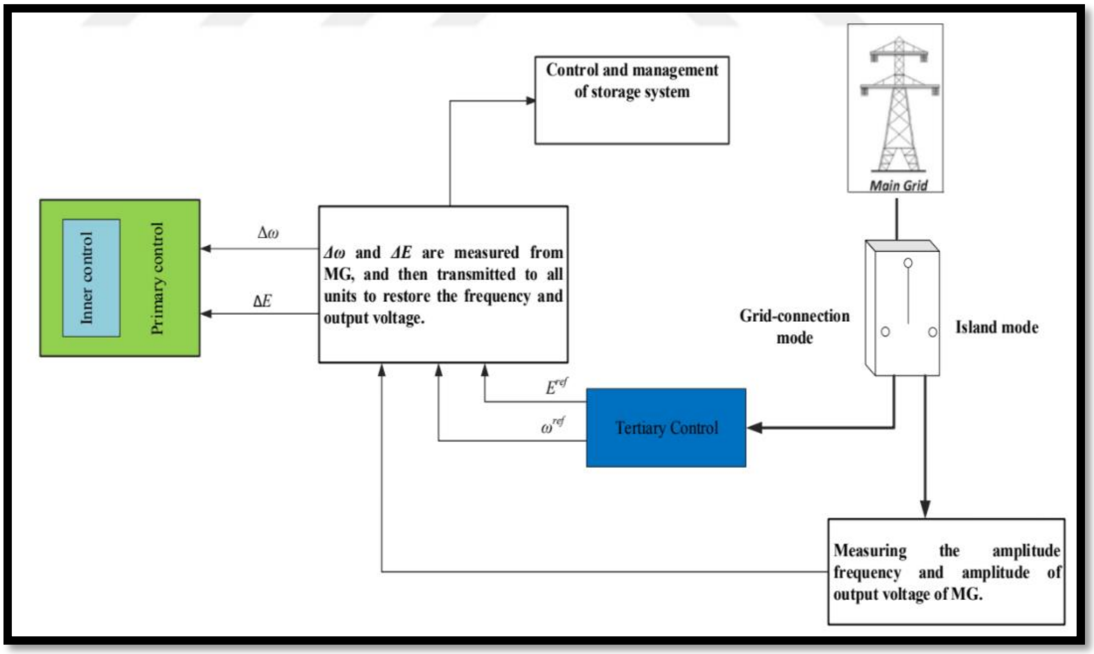


Figure 3.3. The underlying idea of the secondary control method in MGs [54]

i. Centralized Control

This MG control system is frequently carried out with the aid of a central controller, also known as an MG central controller (MGCC). When several devices are networked in different places and their owners' interests are not aligned, such a strategy is difficult to implement. Because it provides trustworthy plug-and-play options, this control form is suited for controlling small MGs with a single or a few DG and ESS owners [68]. Control is centralized or dispersed depending on the MGCC and its location. Figure 3.4 depicts the control structure of centralized secondary MG control. The purpose of this is to measure the frequency/voltage amplitude of DERs and compare it to reference values acquired from the main network (when MG is grid-connection).

When connecting an MG to the grid, the frequency and voltage are monitored since they serve as reference values for the secondary control. When the grid (fs = 0) is removed, the synchronization control loop disables; however, when the grid is connected, a phase-locked loop (PLL) module executes the synchronization, which helps measure the voltage angle necessary for inverter control [69]. According to the preceding explanation, at the secondary control level, the centralized control approach is appropriate for the following MGs [68,70,71]:

- For centralized decision-making and information collecting, small MGs have minimal communication and computing costs.

- All microgrid attributes are predicated on a single goal: to assist the EMS/MGSC, which operates the MG as a whole.

- Military/Defense-related MGs that require strict confidentiality.

- Systems with a set configuration that do not require a lot of expandability or flexibility.

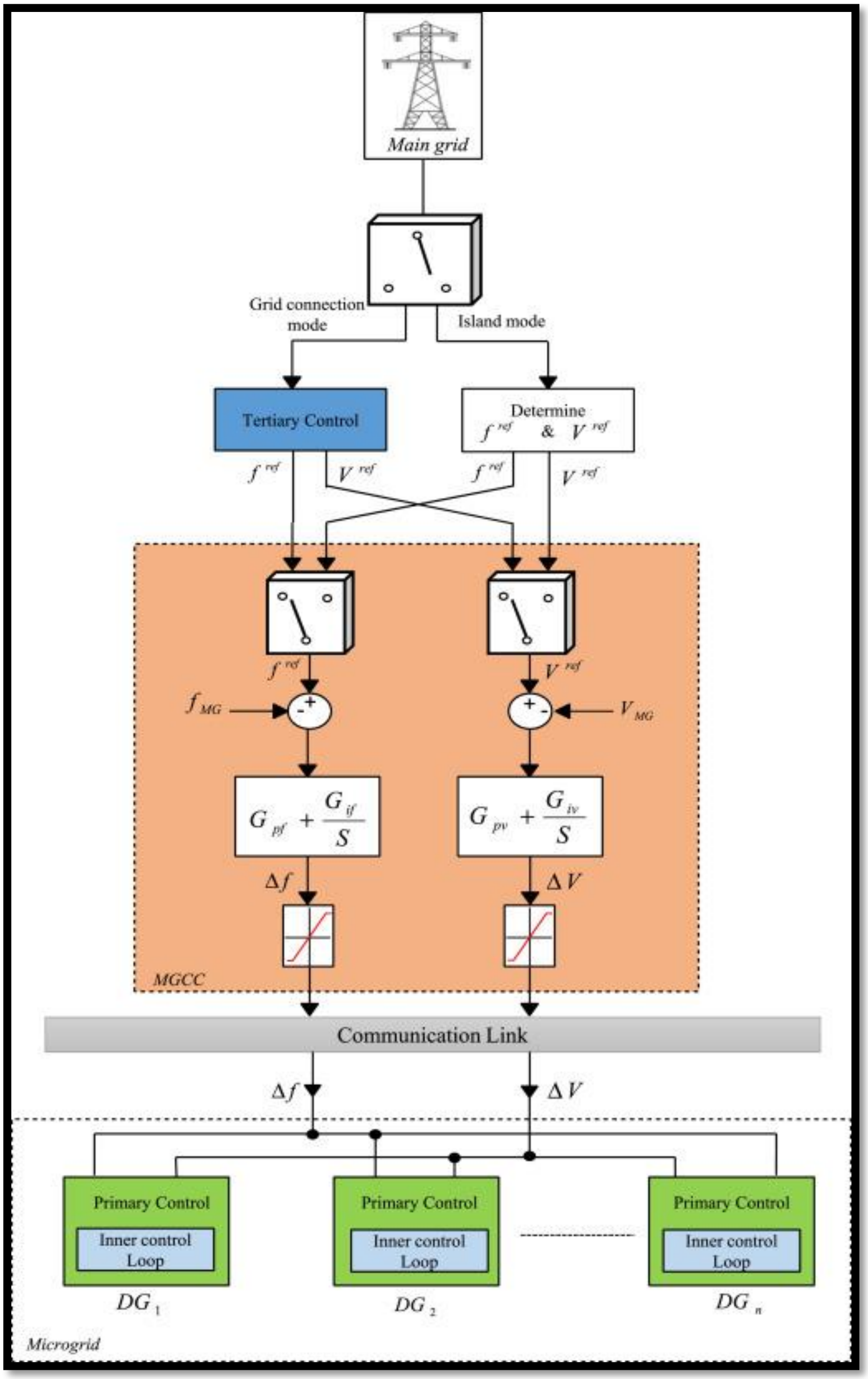


Figure. 3.4. Centralized secondary control structure [54]

ii. Decentralized Control

Decentralized control describes the maximum power that a controller generates while taking the capabilities of the MG into account, which benefits consumers and enhances power addition to the grid. Figure 3.4 displays the secondary controls and their relationship to the principal controls as well as the communication link. [66] Another distributed secondary control strategy that occurs before the communications link and contains a secondary control with each main control. This technique modifies the MGCC's role in controlling and supporting the primary controls. The decentralized secondary control control system, seen in Figure 3.5, monitors the frequency and voltage amplitude across the communication channel. Following that, the average of the recorded values, together with the measurement errors, is passed to the primary control to restore voltage and frequency.

Decentralized control can be accomplished in two ways [72]:

a. Distributed control
b. Decentralized control.

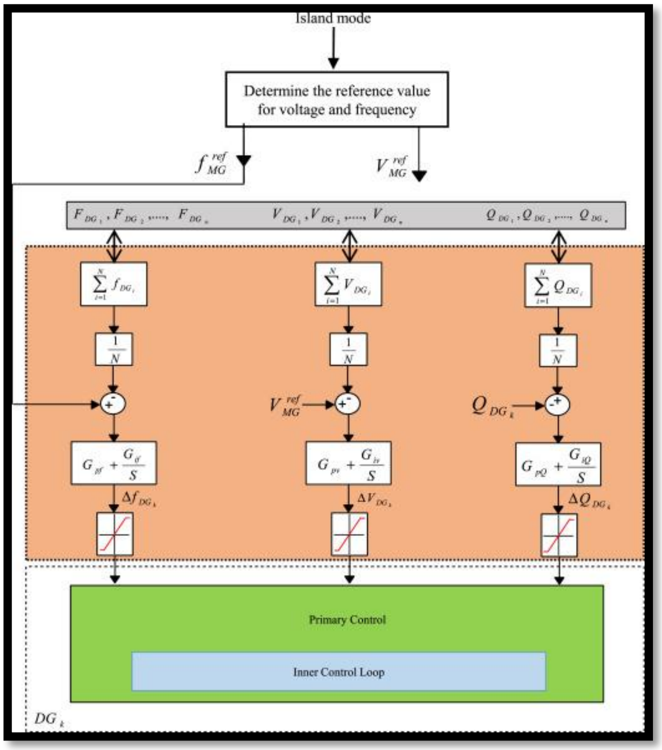


Figure 3.5. Decentralized secondary control structure [54].

a. Distributed Secondary Control

Secondary techniques that perform well and need a relatively modest communication network are researched on a regular basis. Figure 3.6. In [73], the researchers implemented various appropriate alternatives, because of interactions between the MG units, agent-based systems outperform both decentralized and centralized approaches. Multi-agent systems (MAS) offer solutions for MG management that is decentralized. The fundamental principle is that each local controller acts as an agent to manage the DG or ESS unit settings. Because it is a scattered technique, communication occurs only between nearby devices.

According to [74], the MAS-based control algorithm connects with the other components of the MG system through a wireless link. Even when the MG convergence is passive owing to local interferences, the technique enhances MAS-based algorithm performance by lowering multi-agent coordination errors.

Despite MAS-based approaches, there are numerous secondary control solutions for frequency and voltage regulation that provide reactive power-sharing [66,75]. There are three types of strategies: gossip-based (a MAS approach), normal averaging, and consensus-based. The centralized control structure was experimentally compared to the usual averaging control structure. It worked effectively in a research and was proposed as a significantly simplified communication network [66].

Another solution [76] used distributed averages for secondary frequency and voltage management. Each device has a control that requires just the information from the nearby device to exchange power and control frequency. [77] The average voltage sharing adjusts for voltage fluctuations caused by main droop-based regulation.

Voltage and frequency can be restored using a consensus-based secondary control technique, which ensures power-sharing across linked devices [78].

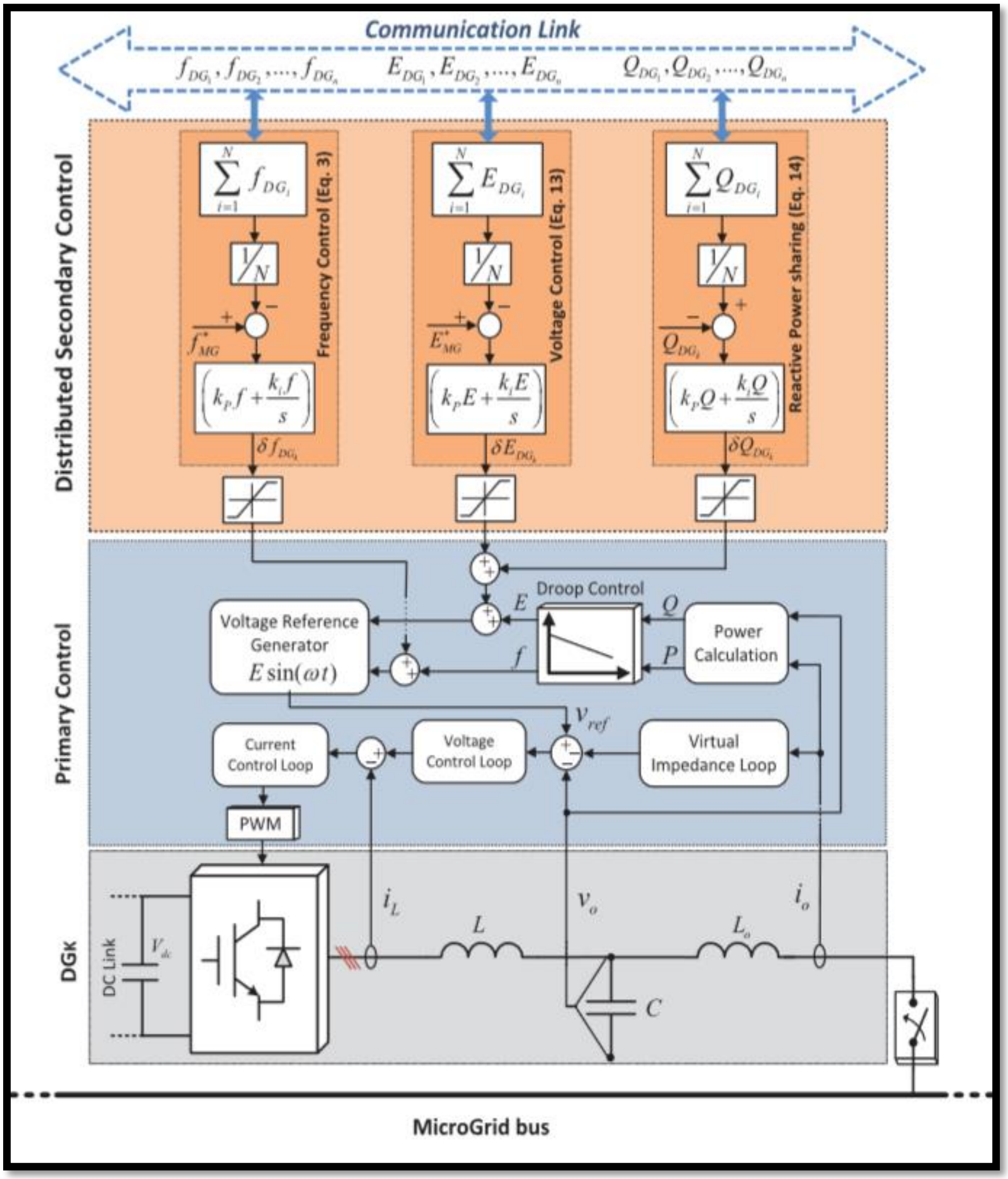


Figure. 3.6 Distributed secondary control [66].

b. Decentralized Secondary Control

Because MGs do not require communication, decentralized control approaches are acceptable, allowing for plug-and-play connections and precise power-sharing despite load variability. Control approaches are governed by parameters that are monitored locally. For ESS unit control, local variables are used in fuzzy inference-based decentralized control systems. For recovering the frequency deviation of the droop main control, a decentralized secondary control strategy is effective.

Furthermore, distributed and decentralized secondary control were compared, revealing that distributed control is more trustworthy and competent than decentralized secondary controls and does not necessitate communication [50, 79]. The centralized approach is effective in the case of MGs only when there is a single owner or when multiple owners have the same interests; thus, it is used for small MGs with few but integrated control-able devices and some anticipated future integrations; however, MGs managed through non-centralized controls have the largest MG applications, as they allow high flexibility through adding or removing some plug-and-play devices. When plug-and-play devices are connected, MGs with decentralized controls may be used in a variety of ways that provide significant flexibility.

3.3.3. Tertiary Control

Tertiary control regulates active and reactive power flows between the main grid and the MG via a grid-tied connection using frequency and voltage regulators. When the PCC determines the P/Q ratio, it compares active and reactive powers to the base values, which are the slowest and ultimate control level. Figure 3.7 depicts a tertiary control scenario. It employs grid-following power converters to achieve the most cost-effective operation [51,58]. When there is a non-plane islanding problem, the tertiary control draws power from the grid. The frequency will be lowered if the grid goes down. When the required value is obtained, the MG disconnects from the grid and disables the tertiary control protocol for safety [53]. Tertiary control, like secondary control, has two applications: centralized (the whole control sits at the MGCC (SCADA system), and distributed (the entire control exists at the local levels).

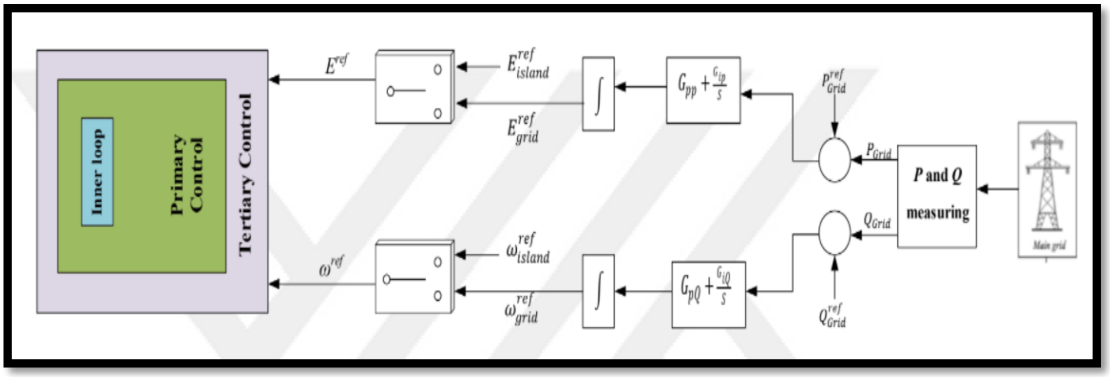


Figure. 3.7. Tertiary control structure in MGs [58]

i. Centralized Tertiary Control

This application requires the PCC to monitor power levels, which are then compared to the predicted results. The P/Q reference values were derived by considering both the microgrid power demand and market concerns (power generation, energy cost, storage, and load forecasting). Several factors, such as economic benefit, efficiency, power quality, and control convenience, can be optimized.

[69] discusses microgrid research that uses tertiary control, whereas MGs' centralized controls have three layers. The result determines how the PCC computes active and reactive powers. In order to create the secondary level reference frequency and voltage values, they are compared to the intended values. The strategy was evaluated using simulations, and the overall control methodology worked well in islanded, on-grid, and transitional scenarios. This technology may also be used to manage a large number of microgrids.

ii. Distributed Tertiary Control

Tertiary controls are rarely directly applied to MGs, although they are a component of the main grid's MGCC (SCADA). Tertiary controls are employed as part of the distributed control of MGs in some circumstances. The study is based on a tertiary gossip-based control algorithm that is placed where the local controllers are. Furthermore, these devices are linked via the internet, increasing the overall efficiency and dependability of the system.

Tertiary control applications greatly increase the adaptability of MGs. A key reason of this is inter-device collaboration among the devices linked to the MG. Such features include demand and generation profiles, projections, MG energy flow, and energy marketing.

4. THE MG APPLICATION FOR BÜYÜKADA AND RESEARCH DYNAMIC

Prince's Islands (Turkish: Adalar) are the subject of cultural, historical, architectural, and most recently energy potential. A research conducted by a fellow researcher proposed the design and architecture of the system of microgrids for Adalar (Büyükada). The software used is HOMERPRO v. 3.14 for the design. Based on the inputs provided, the software can simulate many possible designs to use the mentioned components and suggests the most effective and efficient design in all aspects (both economic and technical).

4.1 HOMER PRO

HOMER Pro® is a Microgrid software package created by HOMER Energy [90]. HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a worldwide standard for developing, modeling, and optimizing MGs. HOMER can simulate grid-connected and isolated mode micro power systems with electrical and thermal demands and any combination of modules such as photovoltaic (PV), wind turbines, small hydro, biomass power, reciprocating engine generators, micro turbines, fuel cells, batteries, and hydrogen storage.

HOMER is in charge of three aspects of the project: simulation, optimization, and sensitivity analysis. Every hour of the year, HOMER replicates the performance of a certain system configuration in order to analyze its technical feasibility and life-cycle cost. Throughout the optimization process, HOMER simulates multiple different system configurations in order to discover the one that fits the technical constraints at the lowest life-cycle cost. In terms of the sensitivity analysis method, HOMER performs many optimizations under various input assumptions to assess the effects of uncertainty or changes in model inputs. The HOMER program is seen in Figure 4.1.

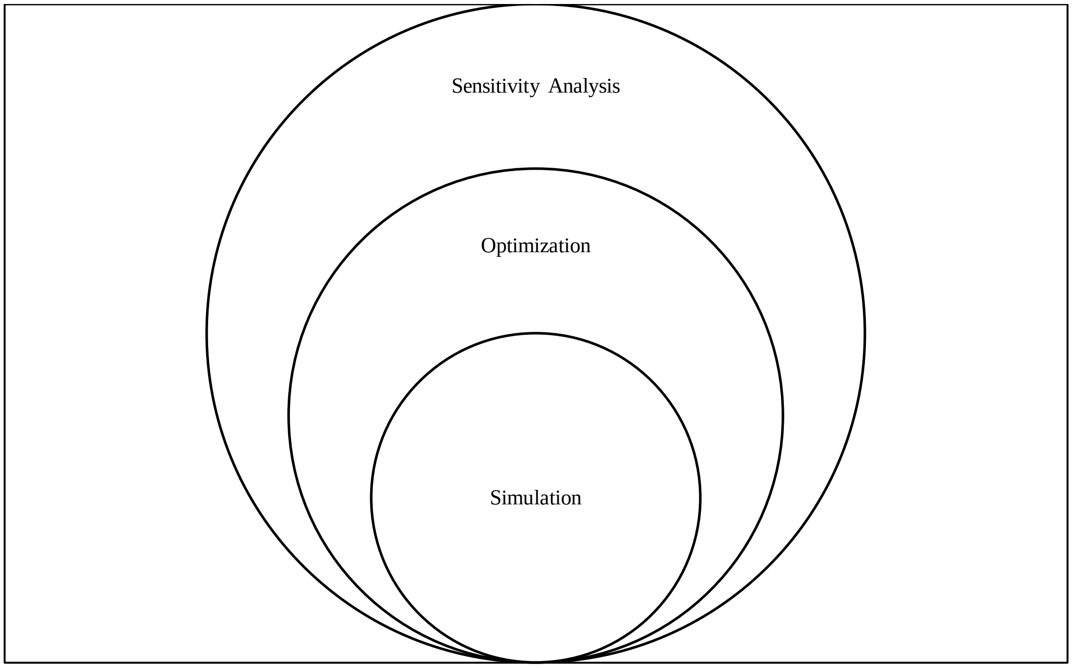


Figure. 4.1 Homer Pro Software

4.2 Methodology (Research Dynamic)

The study started with field trips to the Buyukada for data collection from the municipality and the electrical distribution company AYEDAŞ. Both authorities elaborated on the electricity distribution network and the general data (population, bo. of building, trash collection, disposal, etc.). The data required to predict the electricity consumption and optimize the system was not provided. To extract the data in the form of time series HOMER Pro was used. The software simulated the island's geographical and meteorological conditions with a location in the US and generated the time series. Using the extracted data a total of 4 systems were simulated. the first 2 are base systems (explained below) while the other 2 are optimized systems (explained later). The challenges (environmental, economic, and technical) were addressed in the optimized systems. Machine learning optimization was used to forecast and predicted the electricity pattern of the island.

The study investigated two systems: one with a totally renewable energy strategy and the other with a diesel generator set. Figure. 4.2 (a); (b) as well as Figure 4.3 (a); (b) show the design and results obtained in the case of a pure renewable system and others with a diesel generator.

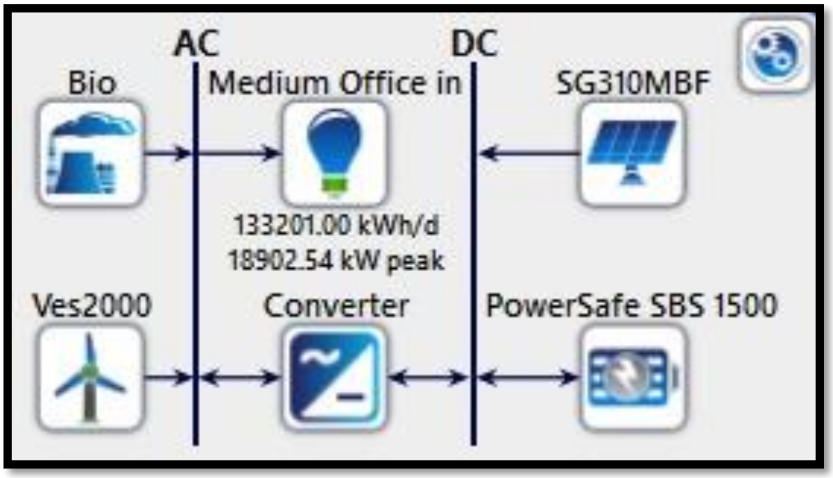
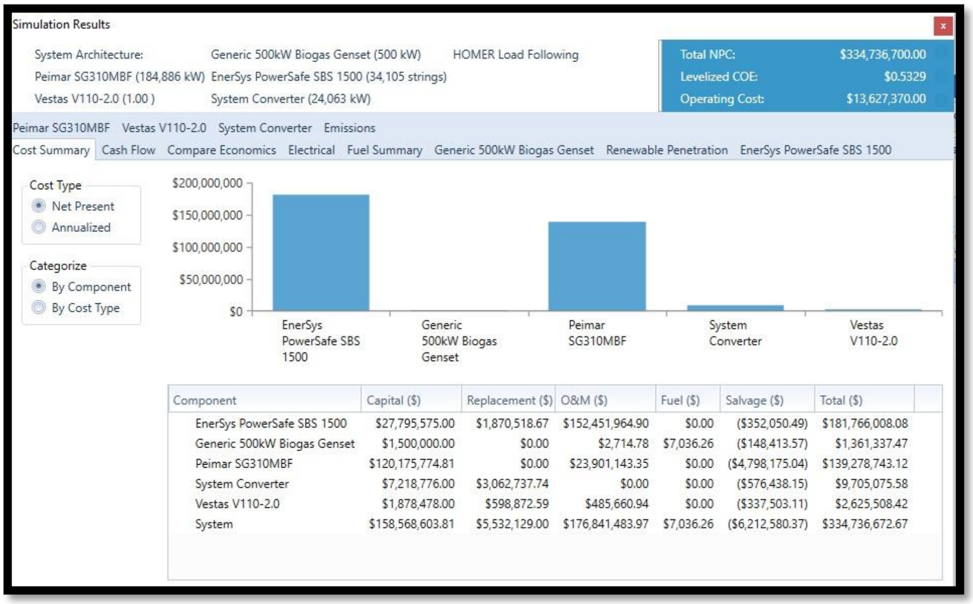


Figure. 4.2 (a) System design with renewable energy resource


Simulation Results

System Architecture:
Peimar SG310MBF (184,886 kW)
Vestas V110-2.0 (1.00)
Generic 500kW Biogas Genset (500 kW)
EnerSys PowerSafe SBS 1500 (34,105 strings)
System Converter (24,063 kW)
HOMER Load Following

Total NPC: $334,736,700.00
Levelized COE: $0.5329
Operating Cost: $13,627,370.00

Cost Type
● Net Present
○ Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
EnerSys PowerSafe SBS 1500	$27,795,575.00	$1,870,518.67	$152,451,964.90	$0.00	($352,050.49)	$181,766,008.08
Generic 500kW Biogas Genset	$1,500,000.00	$0.00	$2,714.78	$7,036.26	($148,413.57)	$1,361,337.47
Peimar SG310MBF	$120,175,774.81	$0.00	$23,901,143.35	$0.00	($4,798,175.04)	$139,278,743.12
System Converter	$7,218,776.00	$3,062,737.74	$0.00	$0.00	($576,438.15)	$9,705,075.58
Vestas V110-2.0	$1,878,478.00	$598,872.59	$485,660.94	$0.00	($337,503.11)	$2,625,508.42
System	$158,568,603.81	$5,532,129.00	$176,841,483.97	$7,036.26	($6,212,580.37)	$334,736,672.67

Figure. 4.2 (b) Results for a pure renewable energy system

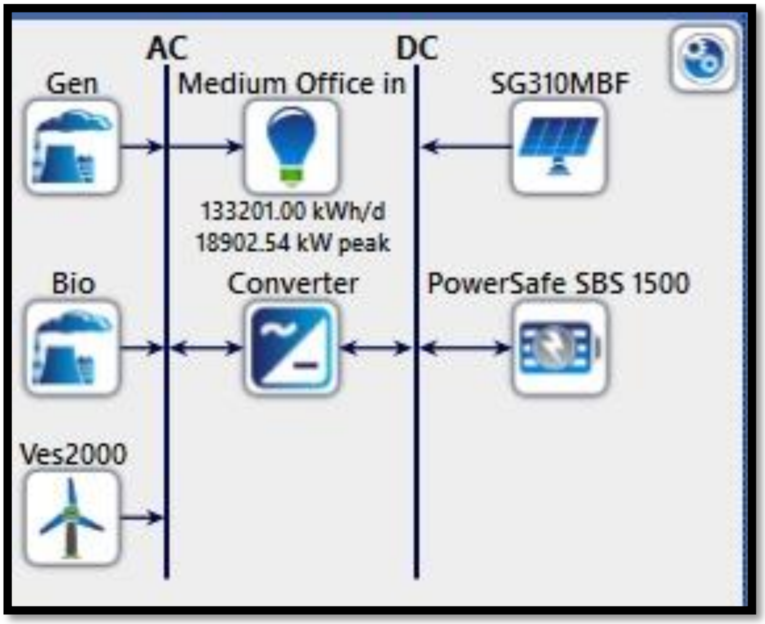
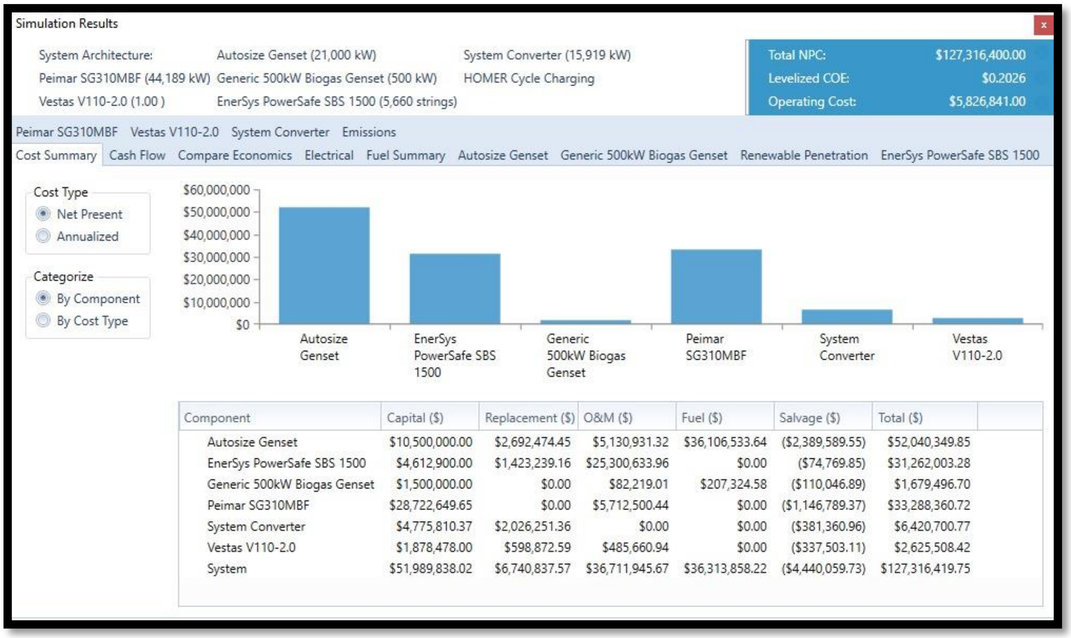


Figure. 4.3 (a) System design with diesel gen set



System Architecture:	Autosize Genset (21,000 kW)	System Converter (15,919 kW)
Peimar SG310MBF (44,189 kW)	Generic 500kW Biogas Genset (500 kW)	HOMER Cycle Charging
Vestas V110-2.0 (1.00)	EnerSys PowerSafe SBS 1500 (5,660 strings)	

Total NPC: $127,316,400.00
Levelized COE: $0.2026
Operating Cost: $5,826,841.00

Cost Type
● Net Present
○ Annualized

Categorize
● By Component
○ By Cost Type

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Autosize Genset	$10,500,000.00	$2,692,474.45	$5,130,931.32	$36,106,533.64	($2,389,589.55)	$52,040,349.85
EnerSys PowerSafe SBS 1500	$4,612,900.00	$1,423,239.16	$25,300,633.96	$0.00	($74,769.85)	$31,262,003.28
Generic 500kW Biogas Genset	$1,500,000.00	$0.00	$82,219.01	$207,324.58	($110,046.89)	$1,679,496.70
Peimar SG310MBF	$28,722,649.65	$0.00	$5,712,500.44	$0.00	($1,146,789.37)	$33,288,360.72
System Converter	$4,775,810.37	$2,026,251.36	$0.00	$0.00	($381,360.96)	$6,420,700.77
Vestas V110-2.0	$1,878,478.00	$598,872.59	$485,660.94	$0.00	($337,503.11)	$2,625,508.42
System	$51,989,838.02	$6,740,837.57	$36,711,945.67	$36,313,858.22	($4,440,059.73)	$127,316,419.75

Figure. 4.3 (b) Results for a diesel gen set system

Both systems are briefly explained below with the pro and cons and the optimized system is explained later.

4.2.1 Renewable Energy system

The architecture in Figure. 4.2 (a) consists of PV system, Wind turbine, Biomass Generator and battery system. Although green energy systems are advancing but they are costly systems. The design suggested is around $334M. The LCOE (Levelized Cost Of Energy) is about $0.5 making the system somewhat feasible Figure. 4.2 (b). The high cost of system is due to the cost of batteries. As the MG is operating in islanded mode, the design includes about 34k battery strings for uninterrupted power supply. Since for renewable energy source generation cannot be controlled but yet can predicted (which will be discussed in the next chapter). The aforementioned case is true for utilization too. If we know the energy usage pre-hand we can use it to change the system characteristics like the load profile and hence the cost can decrease and efficiency will increase.

4.2.2 Diesel gen set

The second architecture Figure. 4.3 (a) was suggested due to the high cost of system 1. Using a diesel generator will not only cut the battery back-up but will reduce the cost too. As shown in Figure. 4.3 (b) the cost reduced to $127M and reducing the LCOE to $0.2. But the diesel generator emits CO_2 too which is increasing in the atmosphere already at an alarming rate.

So, the research was extended to find optimal solution for both environment and economy as it is explained in the later chapters.

5. ENERGY CONSUMPTION FORECASTING

5.1 Introduction to Forecasting

As defined by Wikipedia “Forecasting is the process of making predictions based on past and present data and most commonly by analysis of trends”. As the science and technology is getting better the course of nature is becoming unpredictable. The world experienced an unexpected nature’s preview in the form of COVID-19 pandemic. The pandemic not only changed our course of life but also made us work the ways we haven’t even imagined in the past decade(s). As per pandemic we depended more upon technology. The industries might have a shut down for months suppressing the commercial & industrial use of energy but Residential need had a spike.

The good thing about such scientific spikes is they can be known before they happen. This is done by the use of forecasting and prediction models. Forecasting that is a sub class of prediction to be known in advance about the up comings and to manage the solutions better. As far for electricity the forecasting can be one of many. It could be Electricity Load Forecasting, Electricity Production Forecasting, Price of the fuel (both renewables and non-renewables), Long term (for a year to years to come), Medium term (for months and weeks) and Short term (for days and hours). Forecasting has many algorithms like Machine Learning, Deep Learning, Fuzzy Logic, Reinforced Learning and many more.

5.2 Machine learning

AI is a technology that allows a machine to replicate human behavior. System learning is a kind of AI in which a machine learns from past data without being explicitly programmed. Machine learning is composed of various algorithms that solve complex problems, categorize provided data, manage regression difficulties, and predict future values. A machine learning model is depicted in Figure 5.1.

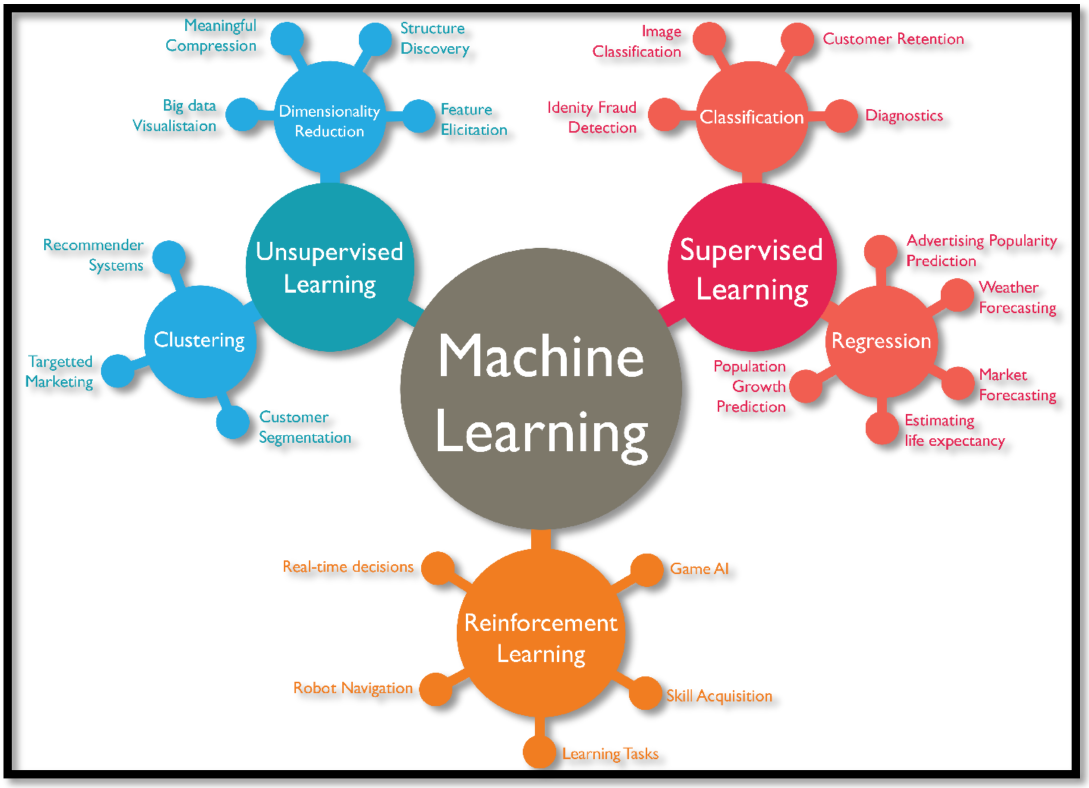


Figure. 5.1 Machine Learning [117]

Machine learning is similar to any other traditional algorithm, yet it varies in a number of ways. Machine learning often employs a series of neural networks known as hidden layers. The action will be performed by the model of hidden layers. We offer the inputs and set of rules for a typical algorithm and receive the output values. The rule box serves as a link between inputs and outputs. In contrast, with a machine learning algorithm, we supply the inputs, potential outputs, and the set of rules that we name machine learning. The notion difference between the two techniques is illustrated in Figure 5.2.

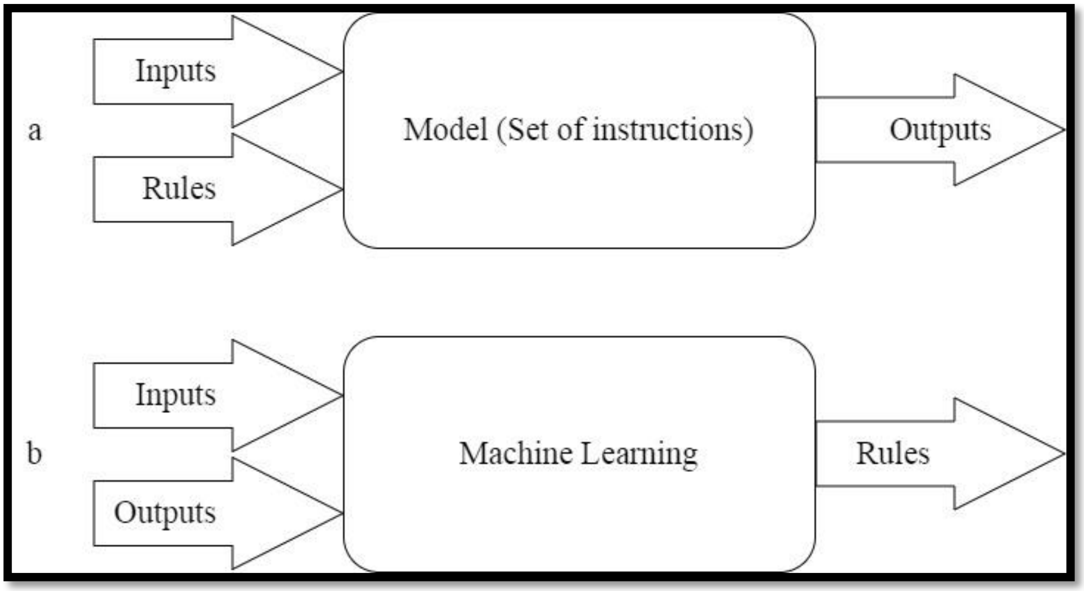


Figure. 5.2 (a) Traditional Algorithm (b) Machine Learning Algorithm

Machine learning further classifies it's domain into two i.e.: Linear/Non-linear Regression which deals the continuous form and one of its use is forecasting. The other one is Logistic Regression which deals with discrete form and use widely for image processing and sorting.

5.3 Neural Network

The most efficient problem solving, act and interact computing device known is "the human brain". The strikingly complex, nonlinear and parallel human brain computer is the inspiration a computer neural network. These algorithmic structures are capable of learning the data provided and predict the future trend, sorting, identification etc. Three things are necessary to represent a neuron:

- Set of synapses: represents connecting connections. The linkages, signals xl, l= 1......L as the l-th synapse's input with weight w_{kl}.

- An adder is used to add the weighted input signals based on their synaptic strengths. The net input of the activation function is adjusted using a bias bk.
- An activation function, ψ(·), or as a squashing function to restrict the output signal's acceptable range.

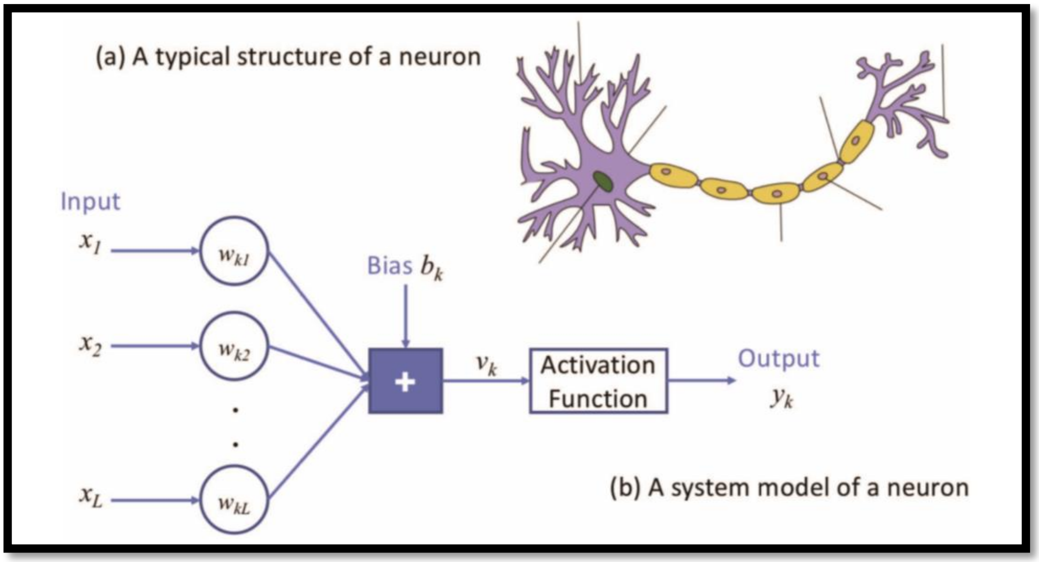


Figure. 5.3 Non-linear model of k-th Neuron. (a) A typical human neuron structure (b) A system model of a neuron. [41]

5.3.1 ANN

ANN began as highly simple models of the human nervous system capable of learning, generalization, and abstraction. Artificial neural networks can not only accumulate, store, and recognize knowledge patterns based on experience, but they can also retrain themselves for a changing environment, with fault-tolerance, efficiency, and self-adaptability, as well as improved cognitive functions like learning and memory [40].

ANN employs non-linear function approximation. It displays the connection between the inputs and the outputs. It is extremely beneficial for predicting, such as the weather and the stock market. This machine learning algorithm is excellent for predicting energy use. The method has three layers: an input layer, a hidden layer, and an output layer. Depending on the algorithm's goal, hidden layers can be any of the following:

- Dense layer (fully connected layer for both forward & backward propagation)
- Convolutional layer (use mainly for image processing)
- Recurrent layer (D- time series)
- Pooling layer
- Many others

Working principle of this algorithm is simple compared to other NN’s. Take the “Input”, “Multiply by Weights”, “plug into the hidden layer with bias”, here it will be multiplied by the activation function and then to the “output”. ANN is like a pendulum, it oscillates forward and backward to find the optimal result.

“FORWARD PROPAGATION” is used to predict the output and “BACKWARD PROPAGATION” for minimizing the loss by updating the weights.

FORWARD PROPAGATION

$$Z = W_i X_i + B \qquad (1)$$

$$\hat{Y} = A = \sigma(Z) \qquad (2)$$

Where:

SIGMOID : $\sigma(Z) = \frac{1}{1+e^{-z}}$

LOSS FUNCTION

$$J = -Y ln A - (1-Y) ln(1-A) \qquad (3)$$

GRAPHICAL REPRESENTAION

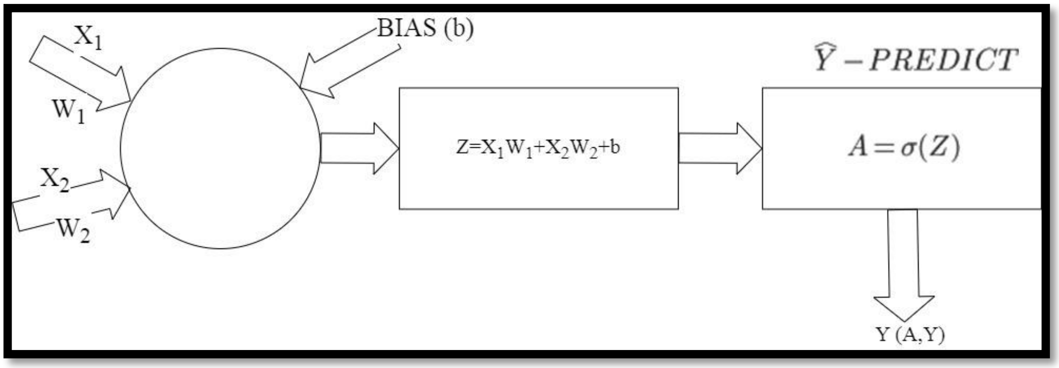


Figure 5.4. Graphical representation of ANN

BACKWARD PROPAGATION

$$\frac{dJ}{dA} = -\frac{Y}{A} - \frac{(1-Y)}{(1-A)} * (-1) \quad (4)$$

$$\frac{-Y}{A} + \frac{1-Y}{1-A}$$

$$\frac{dA}{dZ} = \frac{d}{dZ}\left(\frac{1}{1+e^{-Z}}\right)$$

$$\sigma(Z)[1-\sigma(Z)] \qquad A(1-A)$$

USING CHAIN RULE

$$\frac{dJ}{dZ} = \frac{dJ}{dA} * \frac{dA}{dZ} = A - Y = dZ$$

$$dW_1 = X_1 * dZ$$

$$dW_2 = X_2 * dZ$$

5.3.2 RNN

Another form of neural network is the recurrent neural network (RNN), also known as sequential analysis. It is utilized largely for time series-related problems and sequential modeling difficulties such as dealing with extended variable lengths. There is no sharing parameter and tracking information is in order. It can also help with sentiment analysis and natural language processing.

RNN operates on a closed-loop feedback basis. This feature predicts the output of a selected layer based on its output and feedback. While ANNs have no feedback, RNNs have a feedback mechanism that makes them more powerful. Figure 5.5 depicts the distinction between normal ANN and RNN.

Figure 5.5 ANN vs RNN configuration [118]

RNN can be implemented in a variety of ways, including one-one (single input, single output), one-many (single input, multiple outputs), many-one (multiple inputs, single outputs), and many-many (multiple inputs, multiple outputs) [119]. The mathematical explanation of forward and backward propagation follows.

FORWARD PROPAGATION

$h_t = f_w(w[h_{t-1}, x_t])$ (1)

$= \sigma[w(h_{t=1}, x_t)]$

$= \sigma[w_{hh}h_{t-1}, w_{xh}x_t]$

$y = wh_y h_t$ (2)

BACKWARD PROPAGATION

$w_k = 0$	Vanishing Gradient
$w_k = infinity$	Exploding Gradient

Problems emerge during backward propagation vanishing gradient (when weight=0) and bursting gradient (when weight=infinity). The first issue may be solved by scaling the gradient and utilizing gradient clipping. The aforementioned issue is addressed by changing the activation function, weight initialization, or employing Long-Short term memory (LSTM).

5.3.3 LSTM

The RNN paradigm is supplemented with Long-Short Term Memory networks (LSTM). The method is composed on three basic steps: forget, update, and output. From robot controls and time series analysis to haptic and handwriting recognition, LSTM offers a wide variety of applications. Figure 5.6 depicts the construction of a typical LSTM.

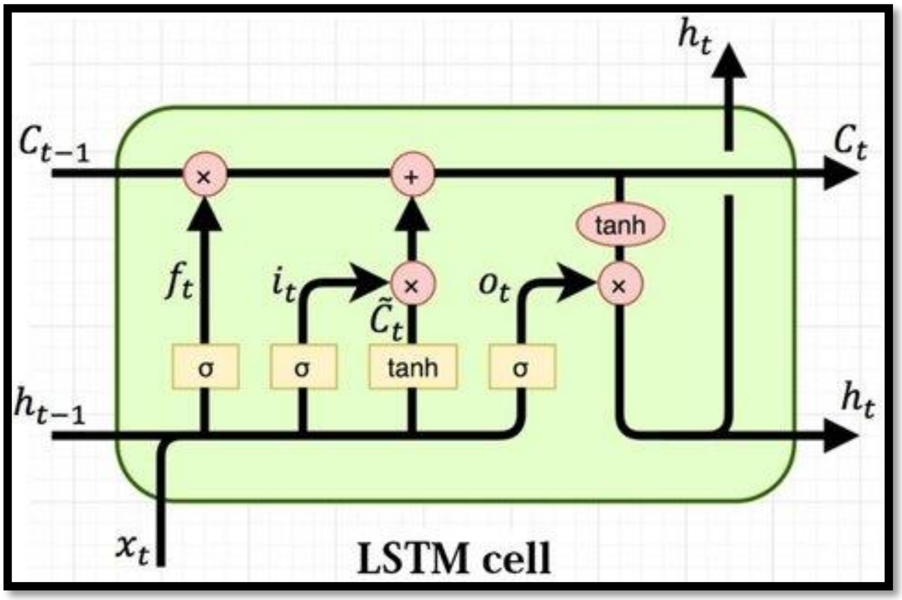


Figure 5.6. A standard LSTM model [120]

The mathematical representation of LSTM stages is defined below.

FORGET

$$f_t = \sigma[w_i(x_t, h_{t-1}) + b_f]$$

UPDATE

$$u_t = \sigma[w_i(x_t, h_{t-1}) + b_i]$$

$$c_t = f_t c_{t-1} + \widehat{ct} * i_t$$

OUTPUT

$$o_t = \sigma[w_0(x_t, h_{t-1}) + b_0]$$

$$h_t = o_t \tanh(c_t)$$

5.4 Energy Consumption Forecasting

As mentioned earlier the electricity consumption data used for this study is extracted by using HOMER Pro which uses the OpenEI database to access the data. This approach was used as the real-time data for the island was not available. Machine learning model "regression" was used to predict electricity consumption. Other models like ANN, RNN, and LSTM can also be used to forecast electricity consumption. After the data extraction HOMER software, it was imported to Google Colab/Kaggle workspace to be used by a regression model. Figure 5.7 shows the graphical energy demand from 2014 to 2019. Next ML linear regression model was built and data was split into train and test data. Entries from 2014-2017 were used as a training set while 2017-2019 data was used as a test set shown in Figure 5.8.

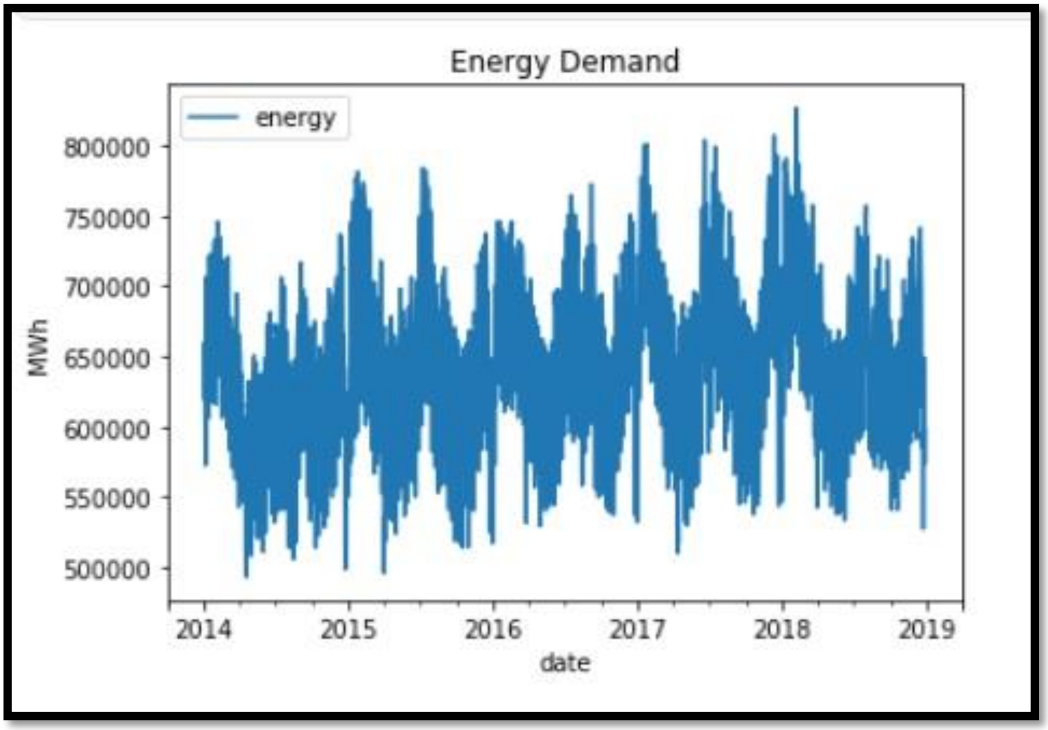


Figure 5.7. Graph depicting energy demand from 2014 to 2019.

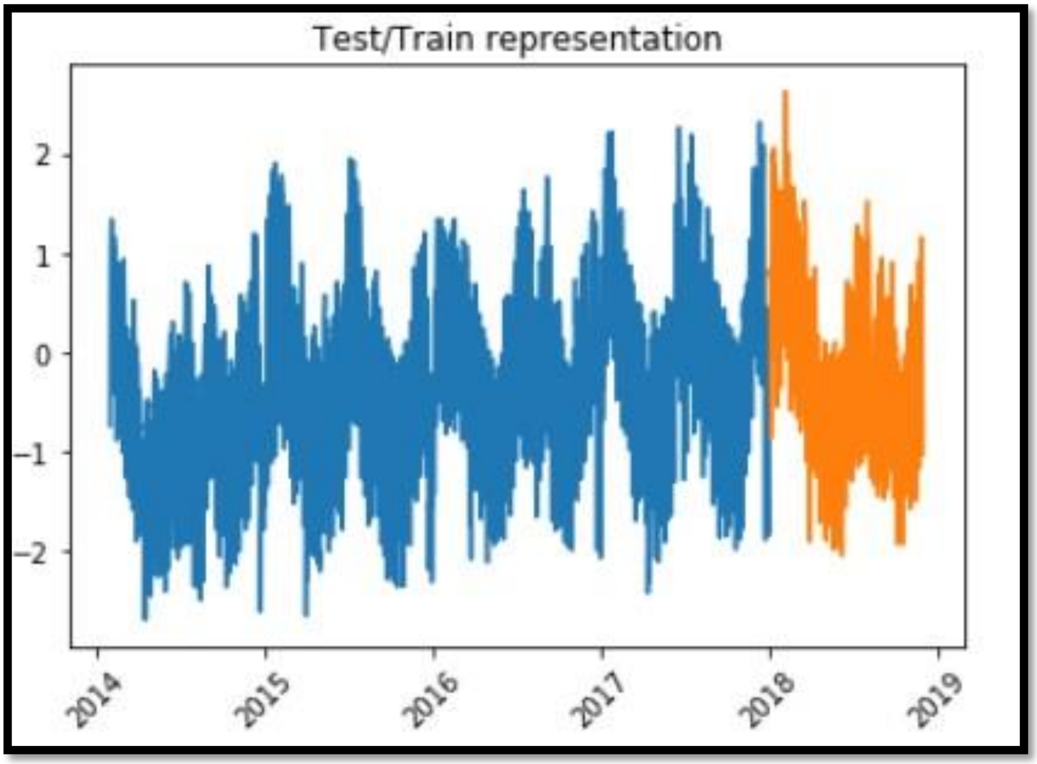


Figure 5.8 Test/Train graphical representation

The forecasted findings are displayed in figures 5.9 and 5.10 below. The model forecasted in the short and medium future. The data provided validated an approximately 91 percent accurate prediction of electricity consumption. The predicted electricity consumption was reduced from 18902.54 kWh to 12567.75 kWh. The peak value was later used by HOMER simulation to simulate the optimized designs. The optimization of the system is explained in chapter 6.

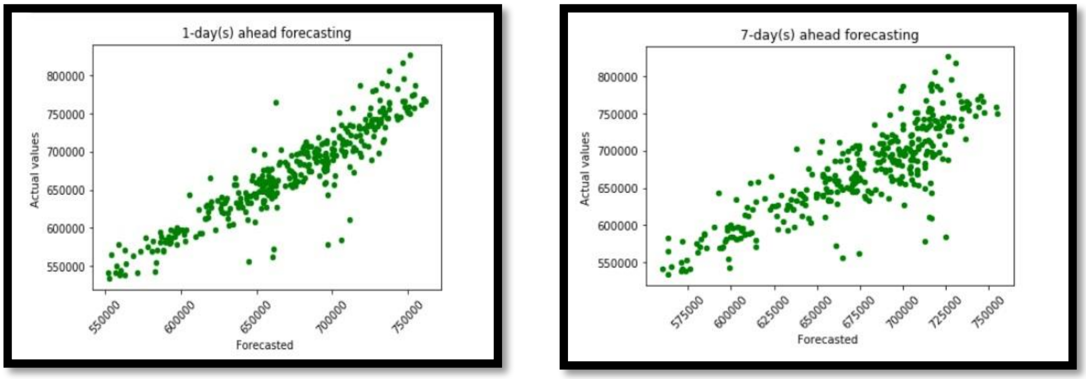


Figure 5.9. Short term (a day and week ahead forecasting)

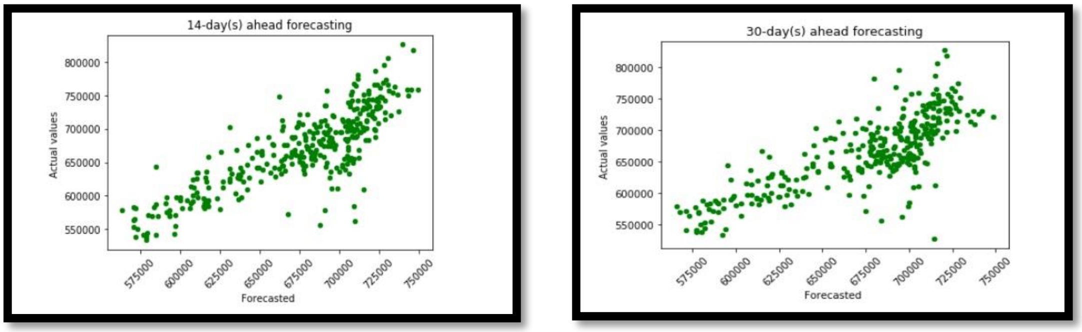


Figure 5.10. Medium term (weekly and monthly forecasting)

The model assessment was performed using MAPE (Mean Absolute Percentage Error). Although RMSE is a prevalent performance metric, MAPE is very suitable and much easier to understand and communicate. It is calculated by using the following formula:

$$MAPE = \frac{1}{N}\sum_{i=1}^{N}\frac{|y-\hat{y}|}{y}$$

For this model, it was around 10% because electricity consumption data has an anomaly due to the COVID-19 pandemic, and the data used to train and test the forecasting is extracted from an Open EI database. Fig. 5.11 represents the error graph between forecasting period vs the percentage for both short and medium term forecasting.

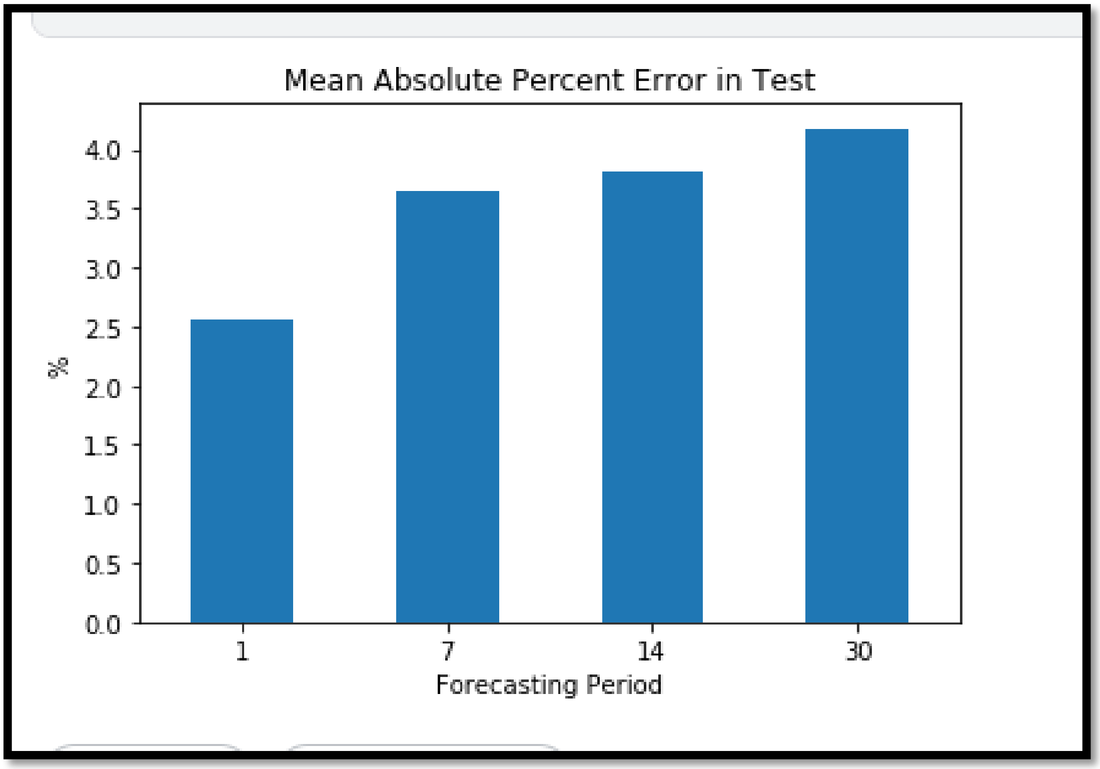


Fig. 5.11. Forecasting vs Percentage error (using MAPE)

6. OPTIMIZATION OF MICROGRID

6.1 Introduction to Optimization

Instead of challenging and time-consuming methods and costly physical testing, a techno-economic study of the MG may be performed using contemporary modeling approaches, which should ensure the reliability of the results. The HOMER program has previously proven to be beneficial in optimization and economic research [91-94].

In this section of the thesis, MG simulation, optimization, sensitivity, and demand response are also done using an MG design proposed by a colleague researcher for Büyükada as an example. The study utilized the island's annual power usage [80] to produce the load profile. HOMER may use manual data provided by the user or the in-built database from places in the United States to construct the data profile. We used the total usage for a homer to construct hourly and monthly consumption profiles because we couldn't collect specific statistics from the distribution firms. As noted in the preceding section, the LCOE of a renewable system is $0.5 while that of a diesel gen set is $0.2. The study's principal optimization is being carried out by applying machine learning to reduce the yearly usage to the expected yearly consumption. The next chapter describes a sophisticated machine learning algorithm.

6.2 Methodology of Techno-Economic Analysis

The licensed HOMER Grid version 3.14 software application provides the secondary technical-economic evaluation of the Microgrid (optimization, sensitivity analysis, demand response). This tool, developed by the National Renewable Energy Laboratory (NREL), covers simulation, optimization, sensitivity, and demand response analysis. HOMER requires a load profile, equipment specifications, meteorological data, economic and technical data, and search space to perform the aforementioned analysis [81, 82].

A flow chart of the technique phases used for thorough analysis is shown in Figure 6.1. These phases include pre- and post-HOMER analysis. The pre-HOMER study gathers and prepares the necessary starting data for simulation in the HOMER software. The program then runs the simulation of the researched MG, optimization analysis, demand response, and MG sensitivity in Post-HOMER analysis.

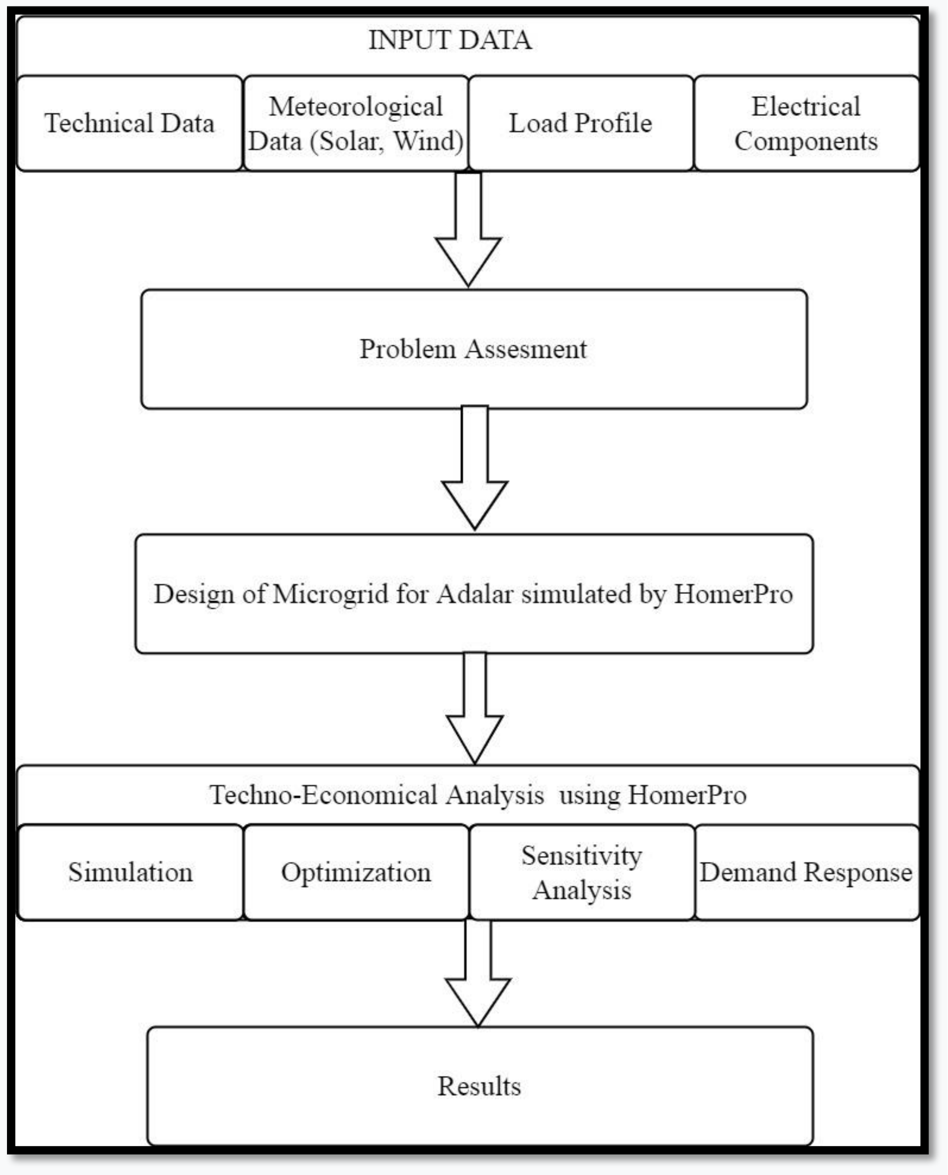


Figure 6.1. The flow chart of the MG analysis optimization technique processes.

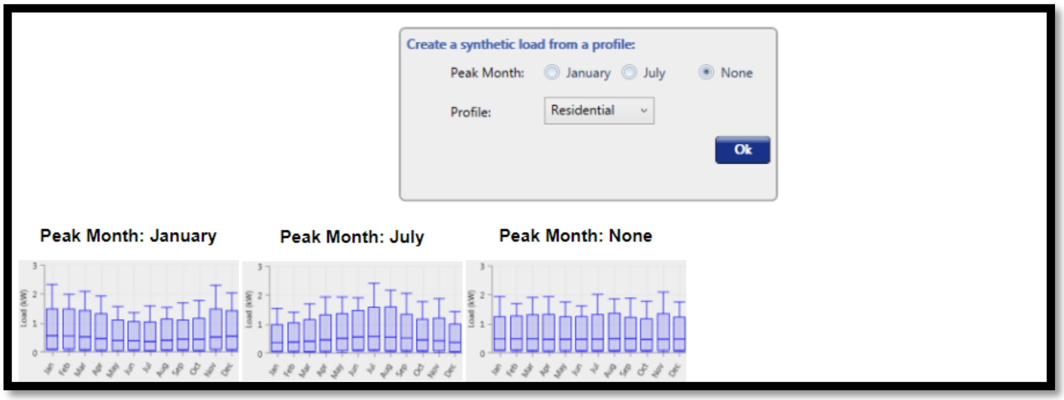
Data is collected during the pre-HOMER phase in order to do a techno-economic evaluation in the post-HOMER phase. Detailed load profiles, equipment specifications, technical data, and climatic data are collected during the pre-HOMER phase.

The viability of key renewable energy sources such as wind and solar energy utilized in the Adalar region of Istanbul province is studied using Global solar and wind maps [95, 27]. As input data for HOMER's techno-economic processing, meteorological data (solar radiation and temperature), load profiles, and technical data were obtained via UTILITY API HOMER (a component of HOMER PRO).

In terms of technology and economics, both islanded and grid-connected MG system operation are evaluated. To optimize system design configurations, the objective function to limitations ratio is reduced. The aim function in this study is total net present cost (NPC), which is the system's current cost minus the sum of revenues. Among the constraints are battery charging and discharging, power balance, and other technological limitations. HOMER simulates system configurations by estimating the maximum number of electric loads per hour that a system can supply by doing an energy balance for each hour.

6.3 The Load Profile

Homer requires a time series profile to simulate the system. This can be done in three possible ways suggested by the software [96]. To start with a user can “Create a Synthetic Load from a Profile” which is a quick and realistic way to generate a load [97]. Based on geography the peak electricity usage month can be selected as shown in Figure. 6.2.



Create a synthetic load from a profile:

Peak Month: ○ January ○ July ● None

Profile: Residential

Figure. 6.2. Creating a synthetic load profile with peak electricity consumption [97].

Varying from project to project the profile can be changed as Residential, Commercial, Industrial, and Community or can be left blank. After selecting the type of load it can be scaled manually by adding "Scaled Annual Average (kWh/day)" as shown in Figure. 6.3.

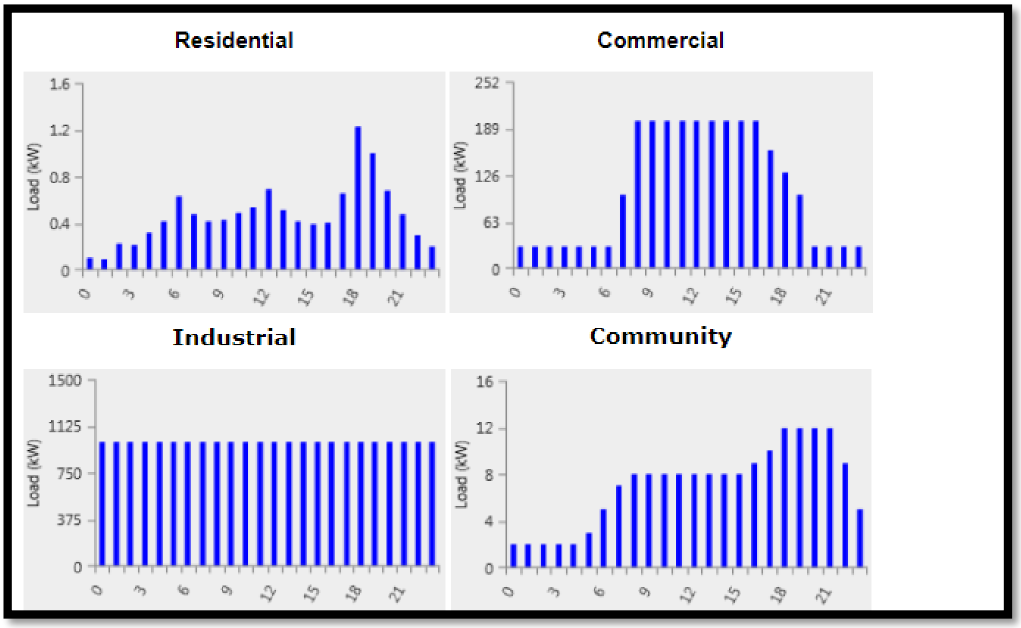
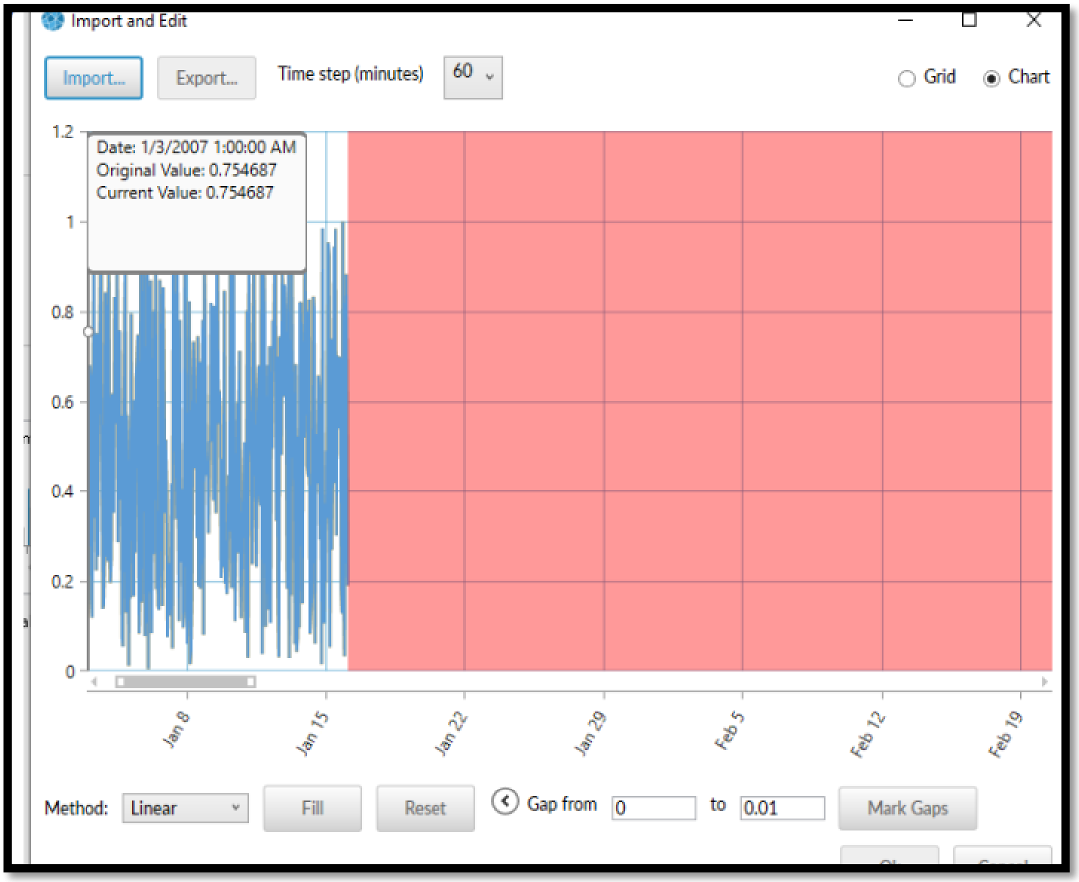


Figure. 6.3. Types of available load profiles [97]

The next load profile can be manually imported and edited as a time-series file. The gaps can be filled by “zeros or by linear interpolation”. HOMER detects the row operation of the file. An 8760 line is considered hourly data whereas 35,540 lines of data are assumed to be 15- minute interval data. Figure. 6.4 demonstrates the manual data window offered by HOMER with linear interpolation [98].



Import and Edit

Time step (minutes) 60

○ Grid ● Chart

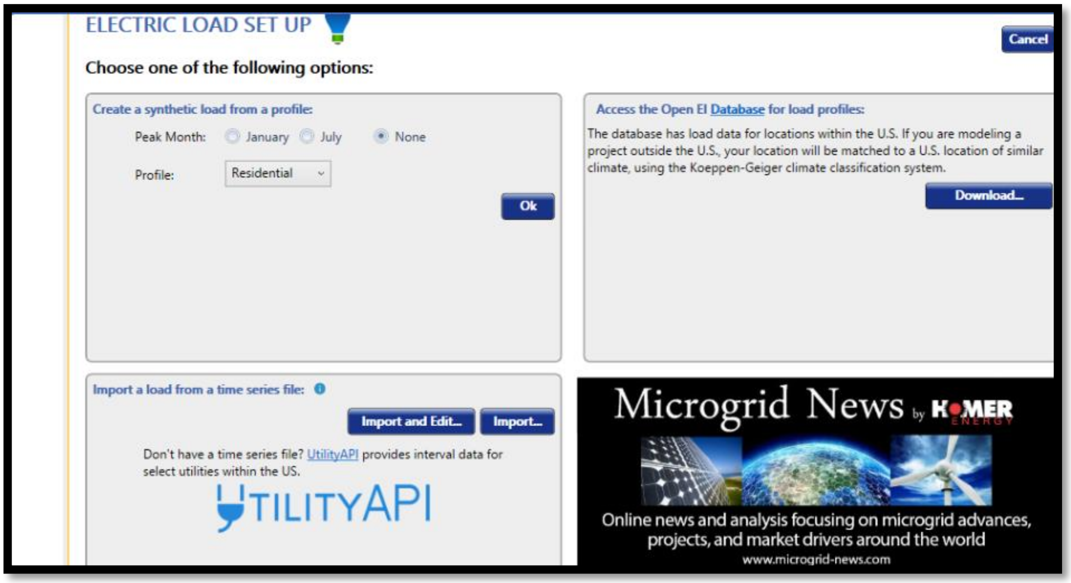
Date: 1/3/2007 1:00:00 AM
Original Value: 0.754687
Current Value: 0.754687

Method: Linear

○ Gap from 0 to 0.01

Figure. 6.4 Manual data import and edit [98].

To sum up the load profile option the last possibility is to extract the data by clicking “Access the OpenEI Database for load profiles” [99]. This feature allows extracting the load profile from the open energy consumption database in the US. Since the software is designed considering US standards and climatic conditions, the project's location is matched with almost similar locations in the US. Figure 6.5 shows all the possible ways to create a profile. For this research data used is extracted by the OpenEI database as the collection was real-time data was not feasible.



ELECTRIC LOAD SET UP

Choose one of the following options:

Create a synthetic load from a profile:

Peak Month: ○ January ○ July ● None

Profile: Residential

Access the Open EI Database for load profiles:

The database has load data for locations within the U.S. If you are modeling a project outside the U.S., your location will be matched to a U.S. location of similar climate, using the Koeppen-Geiger climate classification system.

Import a load from a time series file:

Don't have a time series file? UtilityAPI provides interval data for select utilities within the US.

Online news and analysis focusing on microgrid advances, projects, and market drivers around the world

www.microgrid-news.com

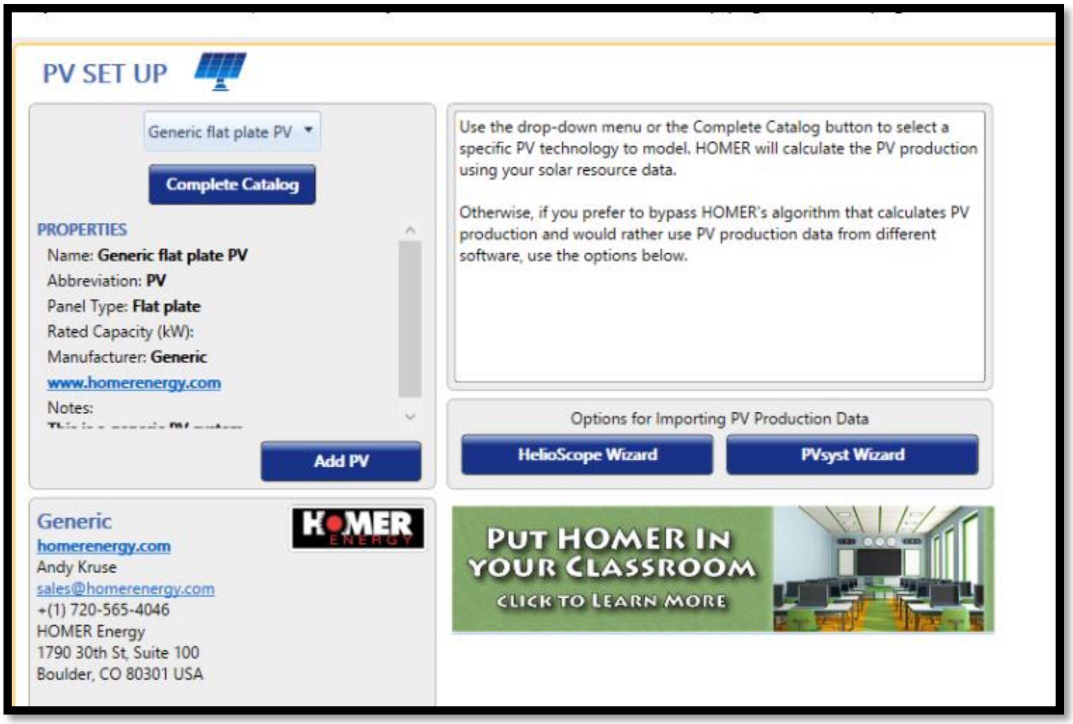
Figure 6.5. The Load profile setup [99].

6.4 The Electrical Equipment

Based on the load profile and the natural resource data (as elaborated in ch#2) electrical equipment like PV panels, Wind turbines, battery systems, and generators (both backup and biomass) were selected. The component selection can be made in the "Component tab" which allows adding or removal of the component from the software's library [100]. Each component's search space allows the user to add manual features like the Net Present Cost (NPC), Operational Cost (OC), and Replacement Cost (RC). The project's estimated lifespan is 25 years for the given conditions. Components used for this research project are PV panels, Wind turbines, battery storage systems, system inverters, and the grid connection. Each component is explained below individually.

6.4.1 The PV Panels

HOMER’s PV selection allows entering features like cost, the orientation of the modules, and size and allows a variety between flat plate and concentrating PV modules from the library. To simulate the solar output precisely PV modules require the data tabs for inverter, MPPT, advanced inputs (Solar GHI and DNI) for the selected location, and the temperature profile of the project’s site. Similar to load profile, solar data can be imported manually by the user or using software like “HelioScope” and “PVsyst”. The data can be extracted automatically by the HOMER’s database collaborated with NASA [101],[102],[103]. PV setup is shown in Figure. 6.6.



Name: Generic flat plate PV
Abbreviation: PV
Panel Type: Flat plate
Rated Capacity (kW):
Manufacturer: Generic
www.homerenergy.com
Notes:

Use the drop-down menu or the Complete Catalog button to select a specific PV technology to model. HOMER will calculate the PV production using your solar resource data.

Otherwise, if you prefer to bypass HOMER's algorithm that calculates PV production and would rather use PV production data from different software, use the options below.

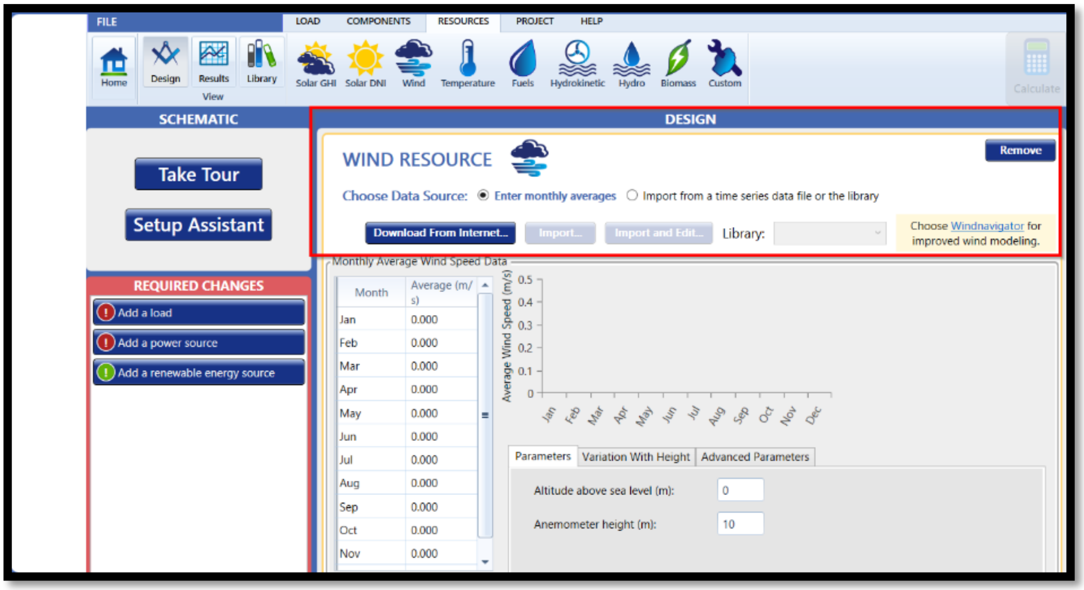
Generic
homerenergy.com
Andy Kruse
sales@homerenergy.com
+(1) 720-565-4046
HOMER Energy
1790 30th St, Suite 100
Boulder, CO 80301 USA

Figure. 6.6. PV resource setup

6.4.2 The Wind Turbine

Unlike PV Wind turbine setup requires access to power curve, turbine losses, cost, wind speed, wind density, and hub height data to model an appropriate wind turbine model.

Monthly wind speed average (as mentioned in ch#2) and wind density data are crucial to designing any wind turbine project. All this data can be accessed by using "Wind Resources" as shown in Figure. 6.7.



WIND RESOURCE

Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Wind Speed Data

Month	Average (m/s)
Jan	0.000
Feb	0.000
Mar	0.000
Apr	0.000
May	0.000
Jun	0.000
Jul	0.000
Aug	0.000
Sep	0.000
Oct	0.000
Nov	0.000

Altitude above sea level (m): 0

Anemometer height (m): 10

Figure. 6.7 Wind turbine setup [104]

6.4.3 The Generator

The program can simulate a generic 1kW generator [105]. The generic generator is diesel-powered and is an emergency backup to renewable resources. The generator model uses fuel resources (present fuel cost), emissions (greenhouse gases production due to burning of fuel), cost, operational and maintenance cost, etc. Users can limit the emissions and hence the operation of the generator will be limited too.

6.4.4 The Energy Storage System (ESS)

Since MGs are powered by renewable energy resources, despite best optimization there is always an element of uncertainty. To eliminate that energy storage system is used. ESS not only ensures an uninterrupted power supply but can also store excess energy. HOMER provides the user with quite many options for ESS. These include battery

(Lead-acid or Li-ion), Supercapacitor, flywheel, hydro pump, or a user-modeled AC coupled battery [106].

6.4.5 The Converter and Control

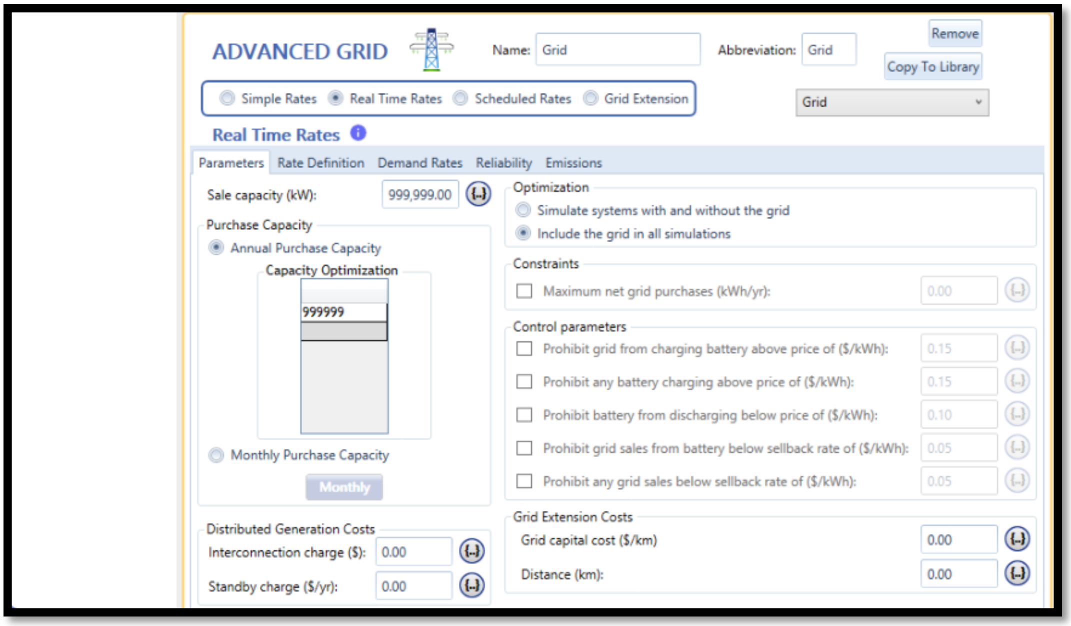
Any hybrid system (consists of both AC and DC bus bars) requires a converter system. HOMER allows users to deal with converter and inverter and rectifier parameters. The input variables include cost, lifespan, efficiency, relative capacity, and custom MATLAB support [107], [108]. HOMER is integrated with MATLAB module which allows the user to simulate any module separately in MATLAB and can use it later in HOMER simulation.'

Since HOMER is a sensitive real-time program it allows a unique control algorithm based on the project's requirement. The controllers include:

- Cycle charging (operation of a generator to ensure ESS levels. Compatible with less or no renewable energy resources) [109]
- Load Following (Renewable energy systems compatible algorithm ensures the uninterrupted power supply by switching the generator on and off) [110]
- MATLAB Link (User-defined) [111]
- Generator Order (used in case of a multi-generator system) [112]
- Combined Dispatch (combination of cyclic charging and load following) [113]
- Predictive Dispatch (Using forecasting algorithms for economical resource usage) [114]

6.4.6 The Grid

MGs can be operated in islanded or grid-connected mode. For the aforementioned case, HOMER allows a grid connection under the "Advanced Grid" option. This feature allows the user to maintain electricity sales and purchase data and hence calculate net metering, real-time electricity trade and electricity pricing, fuel, and other costings related to electricity trade-off. [115].



ADVANCED GRID

Name: Grid

Abbreviation: Grid

○ Simple Rates ● Real Time Rates ○ Scheduled Rates ○ Grid Extension

Grid

Real Time Rates

Sale capacity (kW): 999,999.00

Purchase Capacity

● Annual Purchase Capacity

Capacity Optimization

999999

○ Monthly Purchase Capacity

Distributed Generation Costs

Interconnection charge ($): 0.00

Standby charge ($/yr): 0.00

Optimization

○ Simulate systems with and without the grid

● Include the grid in all simulations

Constraints

☐ Maximum net grid purchases (kWh/yr): 0.00

Control parameters

☐ Prohibit grid from charging battery above price of ($/kWh): 0.15

☐ Prohibit any battery charging above price of ($/kWh): 0.15

☐ Prohibit battery from discharging below price of ($/kWh): 0.10

☐ Prohibit grid sales from battery below sellback rate of ($/kWh): 0.05

☐ Prohibit any grid sales below sellback rate of ($/kWh): 0.05

Grid Extension Costs

Grid capital cost ($/km) 0.00

Distance (km): 0.00

Figure. 6.8. Advanced grid-connected options [115]

7. SIMULATION RESULTS AND DISCUSSION

As a part of an effort toward a green future MG research was suggested (brief overview in ch#4) and extended as a part to optimize the previously suggested designs in both environmental and economic aspects. Greenhouse emissions can be controlled by controlling penetrating renewable energy sources into the energy system infrastructure. These resources require a backup to ensure a steady power supply which increases the cost of the system.

To deal with this dilemma machine learning can be a viable solution as it allows precise prediction for the energy variable. For this research short-term (Hourly and next day) and medium-term (weekly and monthly) forecasting was used. ANN model predicted the energy consumption based on the time series extracted by HOMER using NASA energy data [116].

7.1 Revised Renewable Energy System

ML predicted the energy model for the island and reduced the peak load value from 18902.54kW to 12567.75kW. Using this new peak value HOMER simulated a system with PV, Wind turbine, and ESS as shown in Figure. 7.1.

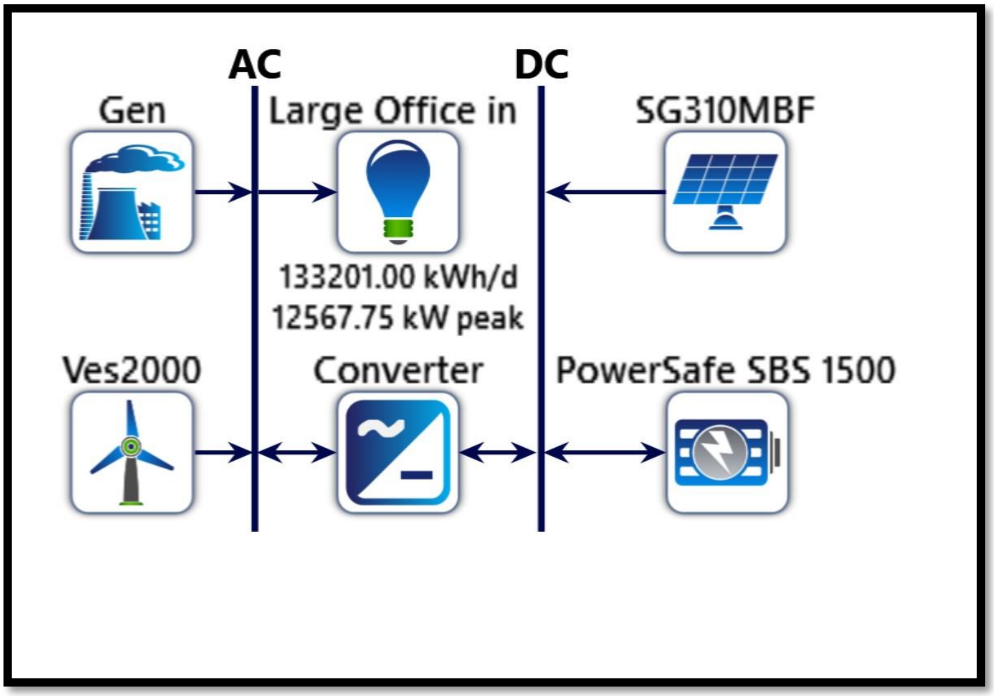


Figure.7.1. The Optimized System

This hybrid system consists of a 1kW *Peimar SG310MBF* PV module connected to the DC bus bar, *Vestas V110-2.0* wind turbine connected to the AC bus bar, a backup diesel generator, *EnerSys PowerSafe* SBS 1500 battery strings connected in parallel to each other. The battery string is connected to the DC bus bar. An auto-switching inverter-rectifier converter for the energy trade-off. The design follows *HOMER Cycle Charging* dispatch strategy to ensure the ESS levels. The overall system costs \$113M with a reasonable \$0.180 LCOE. The annualized cost of this system is \$8.76M which includes operating cost, replacement cost, salvage cost, and resource capital management.

The electrical production summary suggested that the system is powered mainly by PV panels contributing around 83% of the total production followed by gen-set with 9.02% and wind turbine contributing around 7.94%. There is an electricity capacity shortage or an unmet electric load. Simulation suggested that the improvised system has 26,279,381 kWh/yr excess energy. This aspect is dealt with in the next suggested design by connecting the MG to the national grid. The improvised islanded MG diesel generator only worked for 570 h/yr as shown in Figure. 7.2 and hence reduces the overall carbon emissions. ML not only improved the system's performance but also the overall cost is reduced shown in Figure. 7.3. The cash flow for the proposed system is much steadier for 25 suggested years.

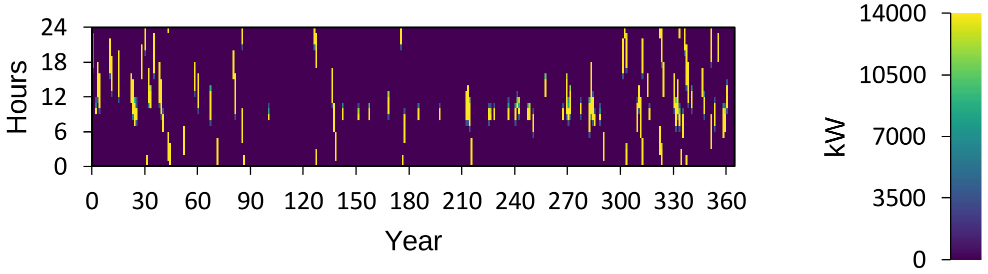


Figure.7.2. Autosize Genset Output (kW)

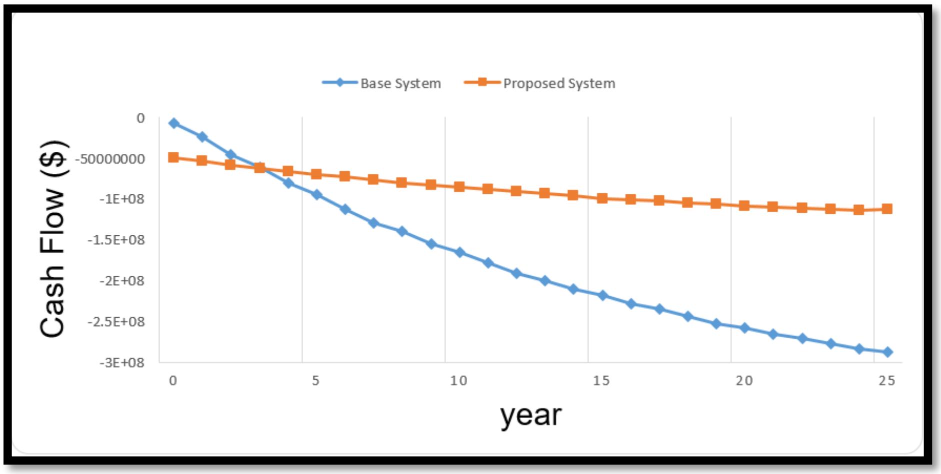


Figure. 7.3. Economy comparison between the base and proposed system. Base system (Blue) vs ML optimized islanded MG (Orange)

7.2 Grid Connected

The system was designed based on the ML values suggested 26,279,381 kWh/yr yearly excess energy. To deal with this surplus two possibilities can be suggested i.e.: the addition of ESS or the interconnection to the electric grid. The battery option has suggested a surplus increase in the system's capital cost. The system suggested in Figure. 7.1 simulated a grid connection using HOMER illustrated in Figure. 7.4.

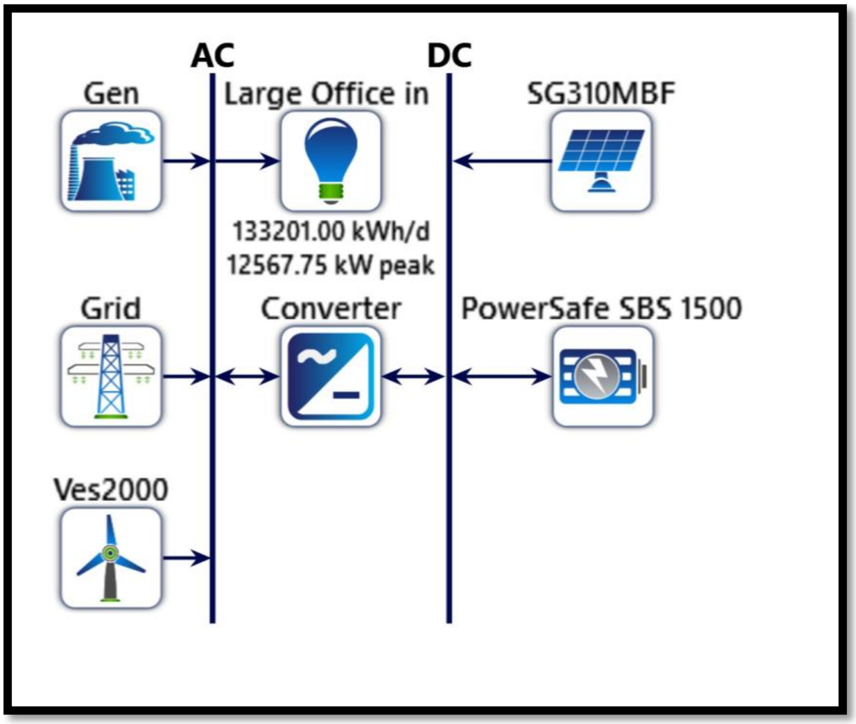


Figure. 7.4 Grid-connected MG

Unlike islanded mode, this grid-connected hybrid system consists of a 1kW *Peimar SG310MBF* PV module connected to the DC bus bar, AC bus bar with *Vestas V110-2.0* wind turbine, a backup diesel gen-set, *EnerSys PowerSafe* SBS 1500 battery strings connected in parallel (with bus voltage as 12 V) to each other. The battery string is connected to the DC bus bar. An auto-switching inverter-rectifier converter for the energy trade-off. The grid module is connected to the AC bus bar to manage the export of excess energy to the utility grid. The design follows *HOMER Cycle Charging* dispatch strategy to ensure the ESS levels. The overall system costs $39M with $0.0429 LCOE. The annualized cost of this system is $3.03M which includes operating cost, replacement cost, salvage cost, and resource capital management.

The electrical production summary suggested that the system has 65% solar-powered following the grid energy for about 26.7% and 8.23% of energy is contributed by the wind turbine. There is an electricity capacity shortage or an unmet electric load. The excess energy trade-off is 2,000,737 kWh/yr. MG is capable of 68.9% of the island's electricity need and the rest 31.1% is fulfilled by the grid sale. Figure. 7.5 (a) and (b) shows the overall grid purchases and sales respectively while Figure. 7.6 suggests the energy trade numerically.

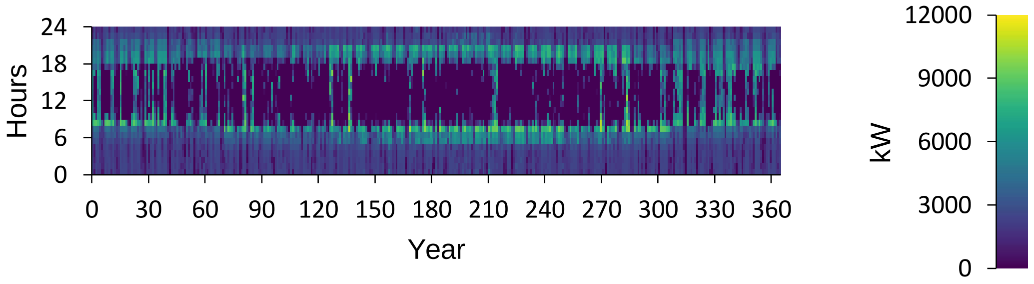


Figure. 7.5 (a) Grid-purchased energy (kW)

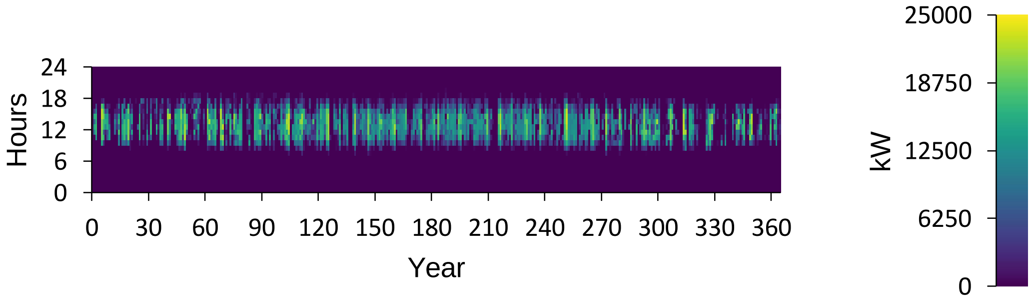
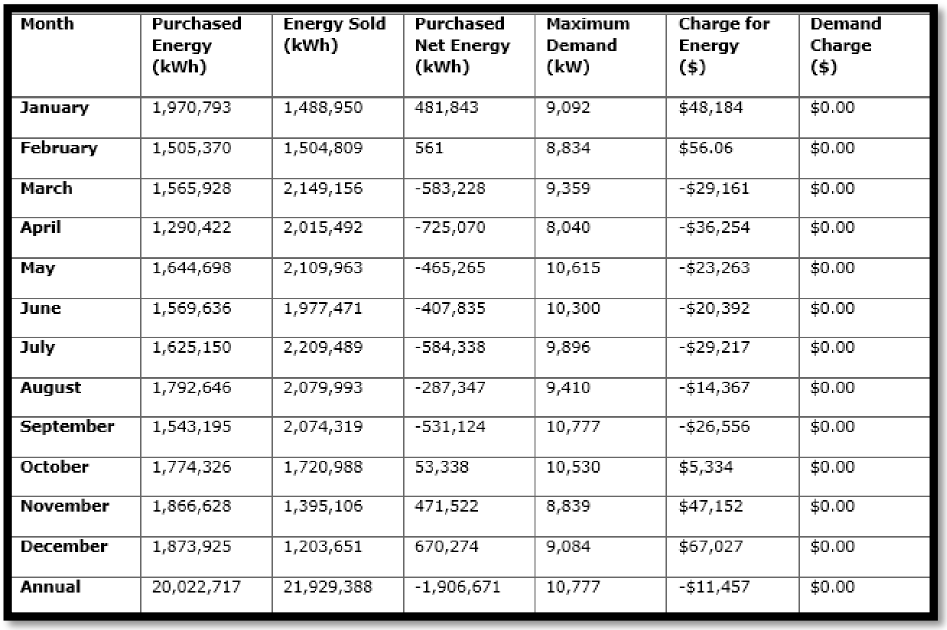


Figure. 7.5 (b) Grid-Sold Energy (kW)



Month	Purchased Energy (kWh)	Energy Sold (kWh)	Purchased Net Energy (kWh)	Maximum Demand (kW)	Charge for Energy ($)	Demand Charge ($)
January	1,970,793	1,488,950	481,843	9,092	$48,184	$0.00
February	1,505,370	1,504,809	561	8,834	$56.06	$0.00
March	1,565,928	2,149,156	-583,228	9,359	-$29,161	$0.00
April	1,290,422	2,015,492	-725,070	8,040	-$36,254	$0.00
May	1,644,698	2,109,963	-465,265	10,615	-$23,263	$0.00
June	1,569,636	1,977,471	-407,835	10,300	-$20,392	$0.00
July	1,625,150	2,209,489	-584,338	9,896	-$29,217	$0.00
August	1,792,646	2,079,993	-287,347	9,410	-$14,367	$0.00
September	1,543,195	2,074,319	-531,124	10,777	-$26,556	$0.00
October	1,774,326	1,720,988	53,338	10,530	$5,334	$0.00
November	1,866,628	1,395,106	471,522	8,839	$47,152	$0.00
December	1,873,925	1,203,651	670,274	9,084	$67,027	$0.00
Annual	20,022,717	21,929,388	-1,906,671	10,777	-$11,457	$0.00

Figure. 7.6 Net energy trade between national grid and MG.

No energy was contributed by the diesel generator so the system can be categorized as a purely renewable system. The advantage of grid connection does not only ensure the power surety but also improves the national grid's energy system by shifting the load from conventional energy production to renewable energy. Figure. 7.7 demonstrates the renewable energy penetration into the national system whereas Figure. 7.8 (a) & (b) illustrate the monthly energy graphically showing the electrical energy drawn (purchased) from and injected (sold) into the national grid.

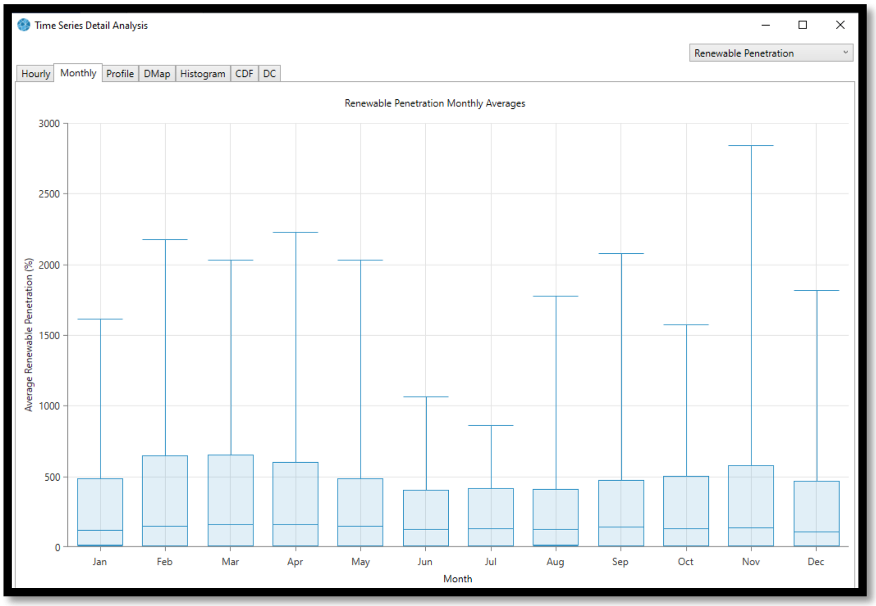


Figure. 7.7 The renewable energy penetration monthly average

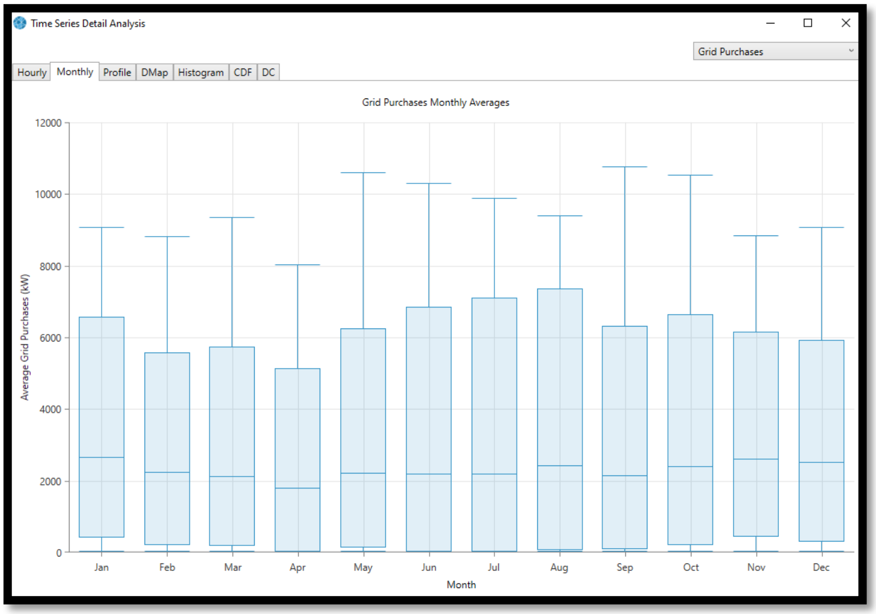


Figure. 7.8 (a). Grid monthly average (purchase)

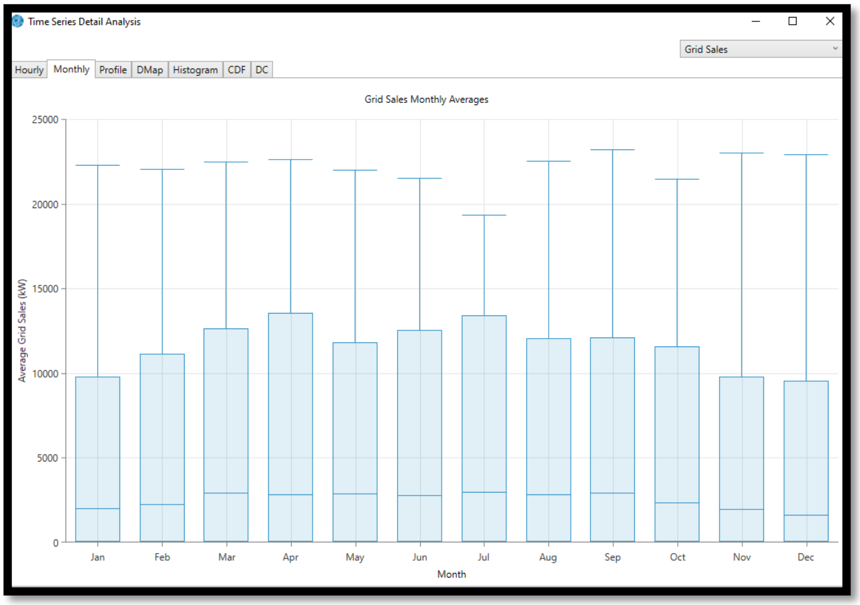


Figure. 7.8 (b). Grid monthly average (sales)

Figure 7.9 depicts the cash flow for the grid-connected system. The grid-connected system is the most optimized and cost-effective of the four solutions proposed.

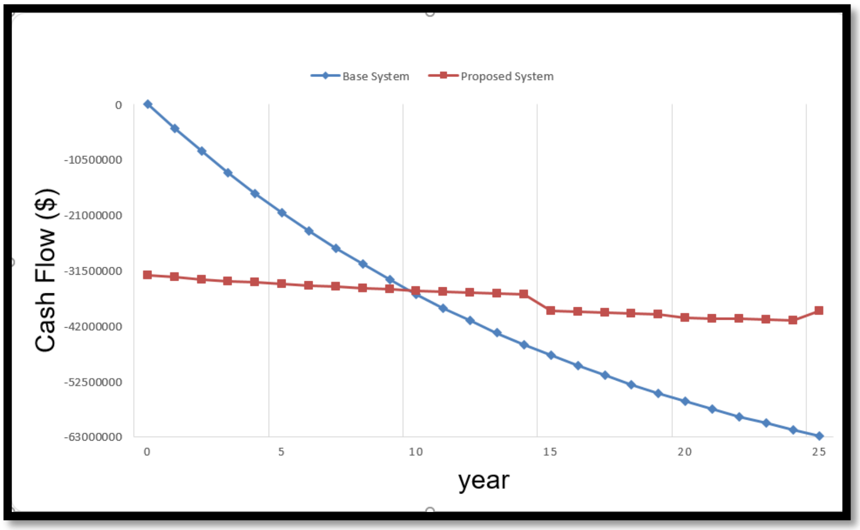


Figure. 7.9. Yearly cash flow for grid-connected system. Base system (Blue) and ML optimized grid connected system (Red)

8. CONCLUSION AND FUTURE WORK

Currently, the main sources of electricity generation are based on hydrocarbon fossil fuels. Though they are quite yielding resources with the hiking prices and shortage of these conventional sources and not to neglect the environmental pollution, these resources are not quite steady for the future. Many countries including Turkey have pledged to contribute to the energy transition from conventional to renewable energy resources. As a result, the modern technological era has come across some low-expense and high-yielding energy solutions.

The MG idea, which has been around for a decade, is a mix of distributed energy resources such as wind turbines, photovoltaics, biomass, geothermal, and storage devices. The system is a distribution and usage network for low and medium voltages. The development of multigenerational systems introduces additional stability and control issues. The problems can be solved by employing sophisticated (fuzzy logic and machine learning-based) control techniques.

During the research following tasks have been carried out:

- Field trip to the project's site (BUYUKADA) to understand the current energy distribution network.
- Collection of data from local municipality and natural resources data from meteorological databases for the mathematical analysis.
- Theoretical and mathematical modeling of MG for the region.
- Simulation of MG using HOMER Pro software.
- Analysis of simulated designs.
- Using machine learning models to optimize the systems.
- Simulation of the revised systems.

- Development of control strategies for both islanded and grid-connected systems
- Techno-economical analysis of optimized systems.

The thesis aimed to control and optimize the base MG system simulated for BUYUKADA. the research aims to the establishment of first MG for the island. The followings are the standouts related:

- Machine learning algorithm ANN was used to forecast the energy peak using the time series extracted by HOMERPro. The predicted peak value was 12567.75kW.
- This value was used to simulate renewable energy-based islanded MG costing \$113M with \$0.180 LCOE. The simulation outcome signified excess energy for which grid-connected MG was designed.
- Grid-connected MG system costs around \$39M with \$0.0429 LCOE.
- Droop control cycle charging algorithm is suggested for voltage magnitude (Q-V) reactive power control at PCC in grid-connected mode.
- Droop control cycle charging algorithm is suggested for frequency (P-f) active power control at PCC in islanded mode.

For future work following approach can be suggested:

- The extension of the study to the neighboring island.
- Introduction of advanced renewable energy resources like aqua-voltics, Agri-voltiacs, etc.
- A cluster of MGs for other regions is connected.
- Improvement in machine learning algorithms and implementation of island's real-time data.
- Integration of the island's EV to the MG as an energy storage system.

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