Analysis of Load Following Strategies for Grid Connected Microgrid having Renewables and Energy Storage

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Declaration

By accepting this research project, I confirm that the research included in this proposal has never before been presented to encounter the criteria for a degree at this university or any other college or university. According to my expertise and judgment, the research work does not use any content that already published or created by another author unless properly cited.

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List of Publications

Conference

- M. Barua, N. Mohammad, S. Mutsuddy, M. A. Razzak, "A Survey of Cross Country Generation Mix - Opportunities and Challenges: Bangladesh, Australia, and the U.S.A Perspectives," *2nd International Conference on Electrical, Computer and Communication Engineering, ECCE 2019*, Apr. 2019, doi: 10.1109/ECACE.2019.8679344.

Approval by the Supervisor

This is to confirm that ***Moon Barua*** completed his research under my guidance and that he met the requirements of the necessary Academic regulations of the Chittagong University of Engineering and Technology, thereby qualifying him to present the corresponding research work in the application for the fulfilment of MSc. in EEE degree.

Professor Dr. Nur Mohammad

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My mother and father (late) had always been an inspiration to me and had given me their love, support, and motivation to get this degree.

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Abstract

Microgrids offer a decentralized source for electrical loads that be able to run either in island approach or simultaneously with the main power grid. A grid-connected microgrid that includes solar panels, four wind turbines, battery storage, and an AC/DC converter has been proposed. Load following method is used as the optimal load-dispatch option to lower both the net present cost and levelized cost of energy of the proposed microgrid. The overall peak load is decreased when a certain electric load is separated as deferrable. This microgrid is connected to the grid, so in a crisis, the system can draw electricity from the grid. It is also feasible to transfer extra electricity to the grid when the microgrid contains more electricity than it needs. The development and refinement of a grid-connected microgrid network using an effective load-dispatch method is explored in this thesis. The performance of the system is evaluated by defining the perfect size of individual elements, doing various cost studies on it, and tracking its responses. The microgrid generates 43,119 kWh of solar energy per year and 137,494 kWh of wind energy per year. In general, 14,440 kWh per year and 127,876 kWh per year of energy is purchased and sold from the grid, respectively. Load following strategies restrict the battery to charge when there is an unmet load in the microgrid. Energy storage device charging is possible only by using renewable energy resources. Besides, deferrable load decreases the system impact of the load during peak hours. The proposed microgrid has the lowest levelized cost of energy of 0.151 dollars than any other combination found during simulation. The thesis result provides a guideline for estimating the components' sizes and probable costings for their optimal operations for any microgrid. Although this study was conducted with specific site data from Bangladesh, the findings apply to any location on the planet with similar geographical conditions and load profiles.

সারাংশ

পাওয়ার গ্রিডের সাথে বা আলাদাভাবে চলতে সক্ষম বৈদ্যুতিক লোডের জন্য মাইক্রোগ্রিডগুলি বিকেন্দ্রীভূত উৎস প্রদান করে। সোলার প্যানেল, চারটি উইন্ড টারবাইন, একটি ব্যাটারি স্টোরেজ এবং একটি এসি/ডিসি কনভার্টারের সমন্বয়ে গঠিত একটি মাইক্রোগ্রিড প্রস্তাব করা হয়েছে। প্রস্তাবিত মাইক্রোগ্রিডের নেট বর্তমান খরচ এবং প্রতি ইউনিট বিদ্যুৎ খরচ উভয়ই কম করার জন্য লোড অনুসরণ পদ্ধতিটি সর্বোত্তম লোড- ডিসপ্যাচ হিসাবে ব্যবহৃত হয়। কিছু বৈদ্যুতিক লোডকে যদি বিলম্বযোগ্য হিসাবে আলাদা করা হয় তবে সামগ্রিক পিক লোড হ্রাস পায়। যেকোন সংকটে সিস্টেমটি গ্রিড থেকে বিদ্যুৎ নিতে পারে, যেহেতু মাইক্রোগ্রিডটি গ্রিডের সাথে সংযুক্ত। মাইক্রোগ্রিডে প্রয়োজনের চেয়ে বেশি বিদ্যুৎ থাকলে তা গ্রিডে স্থানান্তর করাও সম্ভব। একটি কার্যকর লোড-ডিসপ্যাচ পদ্ধতি ব্যবহার করে একটি গ্রিড-সংযুক্ত মাইক্রোগ্রিড নেটওয়ার্কের বিকাশ এবং পরিমার্জন এই গবেষণায় অন্বেষণ করা হয়েছে। প্রত্যেক উপাদানের সঠিক আকার নির্ধারণ করে, এটির উপর বিভিন্ন খরচ অধ্যয়ন করে এবং ফলাফল বিশ্লেষণ করে সিস্টেমের কর্মক্ষমতা মূল্যায়ন করা হয়। মাইক্রোগ্রিডটি প্রতি বছর ৪৩,১১৯ কিলোওয়াট আওয়ার সৌর শক্তি এবং ১৩৭,৪৩৪ কিলোওয়াট আওয়ার বায়ু শক্তি উৎপন্ন করে। গ্রিড থেকে প্রতি বছর সাধারণত ১৪,৪৪০ কিলোওয়াট আওয়ার বিদ্যুৎ ক্রয় এবং ১২৭,৮৭৬ কিলোওয়াট আওয়ার বিদ্যুৎ বিক্রয় করা হয়। মাইক্রোগ্রিডে যখন লোডের চাহিদা অপূর্ণ থাকে তখন লোড অনুসরণ পদ্ধতিটি ব্যাটারির চার্জ হওয়া বন্ধ রাখে। শুধুমাত্র নবায়নযোগ্য শক্তি ব্যবহার করে ব্যাটারি চার্জ করা সম্ভব। এছাড়াও, বিলম্বযোগ্য লোড পিক আওয়ারে সিস্টেমের উপর লোডের চাহিদাকে হ্রাস করে। প্রস্তাবিত মাইক্রোগ্রিডের প্রতি ইউনিট বিদ্যুৎ খরচ ০.১৫১ ডলার যা সিমুলেশনের সময় পাওয়া অন্য যেকোনো পদ্ধতির তুলনায় কম। যেকোন মাইক্রোগ্রিডের সর্বোত্তম কর্মদক্ষতার জন্য উপাদানের আকার নির্ধারণ করা এবং সম্ভাব্য খরচ অনুমান করার জন্য এই গবেষনার ফলাফল একটি নির্দেশিকা প্রদান করে। যদিও এই সমীক্ষাটি বাংলাদেশের নির্দিষ্ট স্থানের তথ্য নিয়ে পরিচালিত হয়েছিল, তবে ফলাফলগুলি অনুরূপ ভৌগলিক অবস্থা এবং লোড প্রোফাইল সহ পৃথিবীর যে কোন স্থানে প্রযোজ্য।

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Nomenclature

Acronyms and Abbreviations

AC	Alternating Current
APSCL	Ashuganj Power Station Company Limited
BD	Bangladesh
BES	Battery Energy Storage Bank
BPDB	Bangladesh Power Development Board
CC	Cycle Charging
CD	Combined Dispatch
CF	Capacity Factor
CRF	Capital Recovery Factor
Converter	System Converter
COE	Cost of Energy
CPGCBL	Coal Power Generation Company Bangladesh Limited
DC	Direct Current
DG	Distributed Energy Generation
DMap	Data Map
EGCB	Electricity Generation Company Bangladesh Ltd.
EO25IIA	Eocycle EO25Class IIA
EMS	Energy Management System
GOB	Government of Bangladesh
GO	Generator Order

GT	Geothermal Energy
HRES	Hybrid Renewable Energy System
IDCOL	Infrastructure Development Authority Limited
LCOE	Levelized Cost of Energy
Iron3500	Iron Edison LFP 3500Ah
LF	Load Following Strategies
NPC	Net Present Cost
NEM	Net Energy Metering
NWPGCL	North-West Power Generation Company Limited
NREL	National Renewable Energy Laboratory
PV	Generic flat plate PV
PS	HOMER predictive dispatch
PSMP	Power System Master Plan
RE	Renewable Energy
SoC	State of Charge
SHS	Solar Home System
Tk	Taka
WT	Wind Turbine
WB	World Bank
WP	Wave Power
WEC	Wind Energy Conversion Unit

Chapter 1: Introduction

Alternators that run on crude oil release a substantial amount of risky conservatory gases into the atmosphere. The Russia-Ukraine war and the COVID-19 pandemic situation unexpectedly worsened the global fossil fuel supply chain. Recently, Bangladesh’s power sector faced unprecedented scenarios, due to high diesel prices and scarcity of furnace oil government had to shut down several power plants. As a result, people are suffering due to load shedding. In this situation, government policymakers are thinking of an alternative way to reduce the power crisis, renewables can be the best alternative for them.

As the stocks of oil and coal are quickly depleting, RE is the answer to the global energy challenges in the days to come. The release of toxic gases as a result of the use of crude oil also highlights the requirement of RE. Microgrids might be regarded as a viable and applicable method for incorporating the decentralized RE into the electric grid. Because of the enormous expansion and development of cities and industries, electricity demand is increasing rapidly. The entire world has already changed its focus to RE like WT, PV, GE, WP, biomass, and hydroelectricity. Some of them, like Solar PV and WT solutions, are much more developed, and accessible, and their portion of global grids and microgrids is growing [1]. Although the fact that current renewable sources are not sustainable for the Bangladesh region. PV appears to have the utmost possibility among the various sources of RE at this moment, with biomass and biogas providing very little usage. BD experiences a mean of 4.5 kWh/m2/day of sun emission every day. Wind energy's possibilities are continuously being investigated. It has been discovered that there are various RE research gaps available in our country. As a solution to this research gap, I have proposed a grid-connected microgrid comprised of renewables and energy storage.

1.1 BACKGROUND

Energy is considered a vital tool for both financial progress and social advancement, resulting in an effective two-way correlation between financial progress and energy use. It is vital to supply the critical energy requirements to achieve persistent GDP expansion of 6% or higher through 2030 and afar. The need for electricity is growing daily. Advancing to an ecological energy future will necessitate improvements not solely in energy delivery, but also in energy consumption. In this context, minimizing the quantity of energy necessary to supply multiple services or products is also a linchpin. The two primary foundations of environmentally friendly energy are believed to be energy optimization and RE [2].

The energy generation mix mostly depends upon fossil fuel-based plants, renewable penetration to the grid is very low in BD. According to BPDB data energy generation fuel mix percentages are such as Coal 7.78%, Gas 51.41%, HFO 27.29%, HSD 5.92%, Hydro 1.06%, Imported 5.34%, Solar 1.19% [3], [4]. To compensate fossil fuel crisis renewables could be the best possible option. Solar and wind could be the best renewable option in our country. Chittagong is a coastal area where solar radiation and wind speed are good. Besides, very little microgrid research is available for Chittagong region though the region has a good potential for renewable energy [5], [6]. I have attempted to create a fresh avenue for researchers and decision-makers to increase their attention to the demand-side management problem and hybrid renewable energy resources. But renewable energy is unpredictable as wind speeds vary from time to time and solar energy extraction at night is impossible. These unpredictable behaviours harden renewable energy reliability and sustainability.

In this study, I have tried to integrate solar and wind energy and store some of it. Bus peak load clipping is made possible in the system by the use of a deferrable load. Peak load could be reduced with effective demand-side management, allowing several peak-load power plants to remain off. The present study analyses demand side management, energy storage, energy sharing, and power generating all at the same time. Taking into account the unpredictable nature of renewable energy, the proposed microgrid could be a dependable and sustainable solution.

1.2 CONTEXT

The major complication linked with renewable power generation is its intermittent behaviour. In gloomy weather solar power generation is reduced significantly and at night time solar power generation becomes zero. This intermittency has a detrimental effect on the stability of the grid. The effect of this intermittency will result in a variable power generation demand in conventional generators. Due to this reason, conventional generators will remain under more stress compared with the situation without any alternative power producer. To tackle this situation, I have included wind generators and energy storage in the system. In some seasons, when solar output becomes low wind energy can compensate for that loss. Though wind energy itself is also intermittent along with solar PV it provides high reliability and dependability.

Demand-side management of the national grid system is not satisfactory. As a result, there is a big difference in load between peak hour and off-peak hour. If it is possible to switch off the deferrable load in peak hours then it could prevent several peak load generators from running. In the proposed microgrid, a deferrable load model has been included in Homer Pro. By simulating in Homer Pro, it is shown that if the consumer runs a deferrable load in an off-peak hour, then peak load clipping is possible.

1.3 PURPOSES

The key objective of the research work is to plan a grid-connected microgrid with renewables and energy storage located in the Chittagong district. To attain this goal, I have split the thesis into several objectives.

1. Research the viability of LF for a microgrid linked to the grid network in Chittagong.
2. To estimate the possibility of wind and solar energy combined with the battery storage capabilities of a microgrid system.
3. Investigate the viability and reliability of integrating RE into the electrical grid.
4. Figure out the consequence of deferred load in the microgrid.
5. Determining the essential financial evaluation and profitability.

1.4 SIGNIFICANCE, SCOPE AND DEFINITIONS

The GOB has launched a variety of programs to increase the expansion of RE. A possible attempt is the enlargement of a RE strategy that needs at minimum 10% of aggregated production to be emanated from it [7]. The goal is not just to minimize carbon dioxide emissions, but to safeguard the nation's security of energy supply. The GOB implemented 500 MW of solar projects in 2012 to encourage RE and attain the RE objective in the total power mix. The private company has been designated as an essential mate in this initiative.

BD encounters a location advantage when it comes to generating electricity from solar and wind energy resources [6]. As per SREDA, the aggregate energy extracted from clean energy sources is 708.19 MW of PV, 2.9 MW of WT, 230 MW of hydro, 0.69 MW of biogas, and 0.4 MW of biomass [8]. Energy harnessing from hydroelectric power plants is almost at its end limit in our country. At present, the renewable energy sector mainly focuses on PV but

Wind energy growth is not that much satisfactory compared to PV. Even though BD holds an anticipated offshore and onshore wind potential of 134 gigawatts and 16 gigawatts respectively [9].

As the proposed microgrid is grid-connected, it is not easy to inject renewable energy into the grid due to the unpredictable nature of renewables. For its simulation, Homer Pro software is employed, which demonstrates that it is feasible to export the surplus RE to the grid network [10]. In the methodology, renewable energy generation, energy storage, energy sharing to the grid and demand side management are discussed in detail. The foremost aim of this study is to emphasize the importance of deferrable load by employing the LF approach for wind and PV plants.

1.5 THESIS OUTLINE

This section focuses on the problem formulation and building the foundation of the reason for doing this study. The literature review mainly discusses the relevance of the work with the works of other authors in the same field. Section **Error! Reference source not found.**, the methodology contains an elaborate description of how we have approached answering the problem statements mentioned in the section of **Error! Reference source not found.**. Section **Error! Reference source not found.**, the results and analysis contain our findings by following the methodology of section **Error! Reference source not found.**. At last, I have summarized the whole work in the conclusion section and pointed out the pros and cons of this dissertation.

In the introduction chapter, I have discussed about power sector of Bangladesh facing various kinds of problems for conventional power plants like as high fuel prices, fuel scarcity, dollar crisis etc. Fossil fuel-based power plant harms the environment. However, microgrids might be regarded as a viable and applicable method for incorporating the decentralized RE into the electric grid. PV and wind appear to have the utmost possibility among the various sources of RE at this moment in Bangladesh. The key objective of the research work is to plan a grid-connected microgrid with renewables and energy storage located in the Chittagong district.

2 Background Theory and Literature Review

As more renewable energy-based generation is used in microgrids, efficient grid-connected microgrid design and operation are becoming more crucial and influential. The main points of all the dissertations consulted regarding the potential for renewable energy and the current situation in BD are summarized in section 2.1. Several pilot projects in BD with project details in subsection 2.1.1 are examined and discussed about upcoming renewable projects in subsection 0. To understand the future trends of renewable energy, refer to the list in

Table 2.1. *Global and BD renewable energy developments have been examined and contrasted using Table 2.2 in part 2.1.2. In section* ***Error! Reference source not found.****, the research gap as well as the benefits and drawbacks of earlier work have been reviewed. The concept of grid-connected microgrids with renewables and energy storage employed in our study was created from these dissertations.*

2.1 PRESENT STATE OF PROBLEM

The government’s goal for clean energy contribution, as stated in the PSMP 2016, is 2,600 MW by 2021 and 7,950 MW by 2041 [7]. Nevertheless, the PSMP goal of generating 10% of the nation's power from RE sources at the end of 2021 was not met, and by the end of 2022, only 950.72 MW of electricity came from renewable sources [8].

Bhuiyan et al. in [6], reviewed the existing RE resources in Bangladesh. In some rural areas and hill tracts supplying grid power is more expensive and tough than installing a Solar Home System (SHS). It can be used for lighting their house so that their children can study at night [11], [12]. However, it has some problems like high capital costs and poor backup time. In developing countries like Bangladesh water irrigation for crop cultivation is a concerning issue as the price of diesel pumps and diesel fuel is high [13]. The solar irrigation pump idea can replace diesel pumps, increasing crop output as a result [14]. Several initiatives for a solar power plant in various region is taken by GOB. In Cox's Bazar district, a 28MW solar power plant already started its operation recently [15]. GOB considering some proposals for solar parks like 200MW Teknaf solar park, 50MW Mymensingh solar park etc. Due to land crisis this kind of theme of solar park whether feasible or not is a big question. Recent research showed Bangladesh has a good potential for wind especially north and south western regions [16]. The northeastern part had an air velocity of 4.5 m/s, while the remainder of the country had a velocity of 3.5 m/s [17]. BPDB selected 22 potential sites to harness the wind energy. BD faces some obstacles to the growth of RE, including the lack of land, lack of funding, and poor climate [6].

In [18] Hossain et al., stated that the most abundant and potentially useful source of RE is solar [19]. In BD, regular solar emission absorption ranges from 4 to 6.5 kWh/m^2, allowing it to yield $1018*10^{18}$ J of energy [20]. GOB has taken several initiatives for renewable energy-related projects across the country. Solar-Diesel Hybrid Solution for Telecom BTS, SHS, Rooftop PV Projects, Solar Irrigation Programs, PV Mini Grid initiatives, etc. [21] [18]. Though feasibility and sustainability study of this kind of projects is not that satisfactory due to low efficiency and high initial capital.

Talut et al. in [22], discussed the potential and impact of industrial building Rooftop solar project in Bangladesh. In [22], the authors also discussed the Net Energy Metering (NEM) system. Under the NEM consumer can sell their excess electricity which is transmitted to the distribution grid and electricity can flow in both directions within the system [23]. Currently, prosumers under the NEM are rising day by day and the total install capacity of NEM users is around 53.546 MWp (January 2023) [24]. Authors calculated roughly 51,961,869 m^2 of roof area is available for rooftop solar PV installation in the 6045 factories around the country so far and it can be a solution for land scarcity for large solar plants in Bangladesh. In [25], the authors observed that 1 KW of monocrystalline silicon solar panels need 7 m^2 of area. Therefore, approximately 7.5 GW of monocrystalline silicon solar PV panels can be installed in the available rooftop of 6045 factories [22]. However, the structural capability for installing large-scale PV above the roof of the considered factories is not evaluated and funding availability of such initiatives is very limited.

In the research work [26], the operation of HRES, which was placed in five distinct regions of BD, was examined both on and off the grid. Depending on the site-specific factors, each region had a unique ideal HRES design as per the author. Furthermore, even though the site-specific control technique was used, its performance may have been improved however particular dispatch method was not defined in the research work [27].

Tanjin et al. in [28], reviewed the wind energy prospects in Bangladesh. According to the author, WT can be constructed along seashores, islands, and at the peak of mountains. The wind travels through BD from February to September at a mean velocity of 3 - 6 m/s. It is generally reduced from the end of September to January and becomes strongest from June to July [29]. Deploying windmills in coastal areas to assist the national electrical grid might be a better choice. In addition to these locations, BD has many hilly areas and uninhabited islands where wind is constantly present at speeds ranging from 2 to 5 m/s. Though the grid accessibility to hill tracks is very tough, wind establishment on hill tracks or remote areas is not economically feasible.

2.1.1 Review of Pilot Project

Shahriar et al. in [30], examined various aspects of integrating a 100 kW WT and a 280 kW PV and a generator combined mini-grid and suggested a projected cost for it on Monpura Island. To conduct the amalgamation of a WEC including the current PV mini-grid, the author covered the alternatives and arguments for several economical solutions. The author suggested various financial scenarios and various system architectures, including Case 1: A PV-WT combined mini-grid plant, depending on the build-own-operate (BOO) framework, is sponsored through a 50% payment, 50% loan and stock. Case 2: The PV-WT combined mini-grid plant is sponsored by 60% grant money, loan and stock money of 40%, depending on the build-own-operate (BOO) framework. Case 3: Two efficient PV mini-grids would be built using the present funding structure of a grant of 50%, a mortgage of 30%, and a stock of 20% of the entire expenditure.

Nandi et al. in [5], a techno-economic feasibility assessment is carried out on a 100kW grid-tied PV and WT setup. Long-lasting weather trends in the islands and along the country's southern coast suggest that the median velocity of the wind is 3 to 4.5 meters per second from the end of February to September and 1.8 to 2.2 meters per second from October to February [31], [32]. The overall quantity of direct solar radiation on the shore of BD varies regularly from 3-11 hrs, based on the long-term standard sunlight statistics. The overall volume of solar irradiance experienced varies between 3.8 to 6.4 kW h/m^2/day globally [33]. Mono-Si-BP4175 solar panels with a 175 W per unit capacity and 12.39% efficiency were used for this study. The total annual simulated output is 148.475 MWh, with the most power produced being around 21.4 MWh and the least produced being around 11.32 MWh. The planned project's anticipated LCOE is 9.68 Tk approximately, which makes it cost-effective against generators.

Ghose et al. in the study [34], designed a solar-wind off-grid solution for a rural area (Parki Sea Beach, Chittagong) [35]. The average global horizontal irradiance at Parki Beach is 4.23 kWh/m^2 and the average daily sunlight is 6.6 per hour. The Weibull distribution of probabilities method was used to assess the wind viability [36]. It calculates that cut-in speed is 4m/s and with a probability of 0.24, we will receive output power 24% of the time. In this case, the author considered about powering of 500 homes. The plant's capacity at a peak value of 45 W is 22.5 kW. This plant generated from WT and PV is around 88929 kWh/yr and 133569 kWh/yr respectively.

Sadrul et al. in [37], for St. Martin Island community energy scarcity settlement, an attempt was made to simulate a combined setup. PV, BES, WT and generator are all used in it [38]. The annual peak load for the island community of 100 homes and 10 businesses is 20 kW, while the daily primary load is 78 kWh. St. Martin Island experiences 4.6 $kWh/m^2/d$ of daily mean radiation, with an average yearly visibility factor of 0.484 [39]. The most economical of all the designs is a combined setup with 25 batteries (800 Ah each), two 3 kW WT, a 15-kW generator, and 8 kW of PV [40], [41], [42]. This setup yields the cheapest LCOE of 26.54 Tk and an overall NPC of 10,620,388 Tk with a 31% RE proportion. Comparing this system to a diesel generator alone, CO_2 emissions can be reduced by around 14 tons annually.

Nandi et al. in the study [43], a WT-PV-BES combined setup was tested to feed a rural village at Sitakunda Upazila, Chattogram, with an annual wind velocity of around 3 m/s. The daily patterns show that the wind velocity is maximum between 12-16 hours and lowest in the early morning [44]. HOMER employs the maximum likelihood approach to fit the recorded wind data to a Weibull distribution [45], [46]. For 120 rural dwellings, the daily electrical consumption is 169 kWh, with a maximum demand of 61 kW. The combined setup is made up of a 225 AH battery segment, a 3-kW WT, and PV rated at 1 kW. WT produces 70.5% of the overall electricity, while PV produces 22.1%. The results of the combined RE setup minimized its surplus electricity to reduce LCOE. The RE potentials have proved that the combined setup designed for the area can fulfil the community's demand for electricity with an LCOE of 0.151 $/kWh.

2.1.1.1 Review of upcoming project

The National Solar Energy Action Plan for Bangladesh unveiled a strategy to modify its renewable energy policies. This is done to install 40 GW by 2041. A medium launch of 25 GW and a regular 8 GW power generation result were also present. As a result, the 40 GW goal, which is based on Bangladesh's capacity for renewable energy, may be difficult to reach in part. The latest data available show that only 3% of the nation's entire power consumption comes from RE.

However, there is the possibility of a rapid shift and a diversity of RE sources. As an example, roughly 500 MW of solar capacity would be achieved by using 1% of the water surface of the Kaptai dam for floating solar. In addition, there is untapped land potential in the Megha estuary's reclamation zones and along riverbanks. Based on information from the NREL, the velocity of the wind covering more than 20,000 km^2 of field ranges from 5.8 to 7.8 m/s. Over 30,000 MW of potential are represented by this [47].

The GOB declared plans to install rooftop PV setups in every educational building to add a greater amount of PV to the power grid [48]. Furthermore, additional electric cars are going to be employed in place of petroleum-based cars. In addition, the country accepted the preliminary 2018 plan meant for the Electric Car Licensing and Usage Guidelines in 2021. As a result, it is planned to construct PV electric charging facilities for EVs with a mean rating of 20 kW [49].

Even though, the foreseeable future is far away, it appears optimistic for the present. As per the REN21 study, BD along with countries such as Japan, Singapore, Malaysia, Indonesia, India and China, is leading the continent's RE growth [50]. A statement by Dandan Chen of WB, BD holds one of the best competent off-grid RE initiatives on the earth, which he acknowledged as a sign of an encouraging trend.

Organizational capability and government strategy will eventually guide BD's transition toward RE. For instance, IDCOL's Solar Home System Programme supports consumers and private businesses in the renewable energy market with money and technical know-how. As a result of such measures, Bangladesh now claims the major local PV platform worldwide, with 11% of its inhabitants covered [51].

As seen in

Table 2.1, Bangladesh is currently proposing several wind and solar projects, some of which are already under construction [52]. If built, the Matarbari 100MW on-grid power station will have the greatest capacity wind turbine in our country. Another high-capacity solar PV plant with a capacity of 120MWp is being built in Raipur, Narsingdi.

Table 2.1 Upcoming renewable project in Bangladesh

SL.	Project Name	Capacity	Location	Agency	Present Status	Grid Status
1	2MW Capacity Wind Power Plant at bank of River Jamuna adjacent to the Sirajgang 150MW power plant.	2MWp	Sirajgang, Bangladesh	BPDB	Implementation Ongoing	On Grid
2	Matarbari 100MW wind power plant project	100MWp	Maheshkhali Upazila, Cox's Bazar	CPGCBL	Under planning	On Grid

3	30MW Wind Power Plant by Bhagwati and Regan Powertech and Siddhant Energy Ltd (India).	30MWp	Sonagazi, Feni	BPDB	Under Planning	On Grid
4	50MW Grid-tied Windmill	50MWp	Chandpur Sadar, Chandpur	BPDB	Under Planning	On Grid
5	Sirajganj 68MW Solar Park (88.75 MWp)	88.75MWp	Sirajganj sadar upazila, Sirajganj	NWPGCL	Implementation Ongoing	On Grid
6	Sonagazi 50 MW Solar Power Plant Construction Project	50MWp	Sonagazi, Feni	EGCB	Implementation Ongoing	On Grid
7	30MW(AC) Solar Park by Beximco Power Company Ltd & Jiangsu Zhongtian Tech. Ltd.	30MWp	Tetulia, Panchagarh	BPDB	Implementation Ongoing	On Grid
8	32MW (AC) Solar Park by Haor Bangla-Korea Green Energy Ltd.	32MWp	Dharampasha, Sunamganj	BPDB	Implementation Ongoing	On Grid
9	Raipur 120MW (AC) Grid Tied Solar Power Plant	120MWp	Raipur Upazila, Narsingdi	APSCL	Implementation Ongoing	On Grid

2.1.2 Comparison

PV and wind power systems were the key solutions to the concerns of secure electricity source, ecological responsibility, and price of energy for many years [53]. Additionally, there are many PV-wind mix plants in nations such as Australia, India, Japan, Germany and China, among others. Although there are not many solar-wind hybrid plants in Bangladesh. The first hybrid solar wind tower in Bangladesh, measuring 75 meters in length, was built by edotco Bangladesh, a provider of comprehensive telecoms infrastructure services, on

Hatiya, an isolated isle upazila of Noakhali district with few commercial electrical supplies [54]. GOB emphasizes solar plants as solar is considered the best option for renewable resources in BD. Table 2.2 includes a comparison chart to help us understand global and Bangladeshi renewable energy trends [52].

Table 2.2 Comparison Chart of Global and Bangladeshi Trends in RE [8].

SL.	Project Name	Location	Size	Mixing	Grid Status
1	Adani 450 MW Solar-Wind Hybrid Power Plant	Jaisalmer, Rajasthan, India	450MWp	420MW Solar + 105 MW Wind	On grid
2	Floating Solar-Wind offshore project by Ocean Sun Ltd.	Haiyang, Shandong, China	302.1MWp	301.6MW Wind+500KW Solar	On grid
3	Tahara city 56MW Solar Wind Hybrid Plant by Mitsui and Toshiba Corp.	Honshu, Japan	56MWp	50MW Solar + 6MW Wind	On grid
4	Baywa RE Solar Wind Energy System	Bayreuth, Germany	34 MW	10MWp Solar +24MW Wind	On grid
5	The Keneddy Energy Park at Flinders Shire	Queensland, Australia	58 MWp	43MW Wind + 15MW Solar	On grid
6	2000 KW Capacity Wind Battery Hybrid Power Plant	Kutubdia, Cox's Bazar	2 MWp	Wind	Off-grid
7	Grid-tied WT at Muhuri Dam	Sonagazi, Feni	900 KWp	Wind	On-grid
8	WT Unit by Green Energy (BD) Ltd.	Chakaria, Cox's Bazar	60 MWp	Wind	On grid
9	30 MW (AC) Solar Park by Intraco CNG Ltd	Gangachara, Rangpur	30 MWp	Solar	On grid
10	Solar Park by Energon Technologies & China Sunergy Co.Ltd	Mongla, Bagerhat	100 MWp	Solar	On grid
11	Kaptai 7.4 MWp (6.63MW AC) grid-tied PV	Kaptai, Rangamati	7.4 MWp	Solar	On grid

12	NEM rooftop PV by Suny Fuels and Polymer Ltd.	Sonargaon Upazila, Narayanganj	550kWp	Solar	On Grid
13	Proposed Microgrid	Sitakunda, Chattogram	1.30 MWp	30 kW Solar + 100 kW Wind	On grid

2.2 PREVIOUS WORK

The proposed grid connected microgrid can meet certain community loads. For the optimization of microgrid Load Following strategy was incorporated in the simulation. Few applicable dispatch strategies and their impact on microgrids are discussed in [55]. In Fig. 2.3 schematic of the research gap of several key papers has been reviewed.

Lipu et al. analysed the viability assessment of a hybrid system of green energy using PV, WT, and diesel that was conducted for isolated and rural regions of BD. After considering several cases, it was discovered that PV, WT, Diesel, and BES combo installations had lower NPC and LCOE ($ 0.27) than

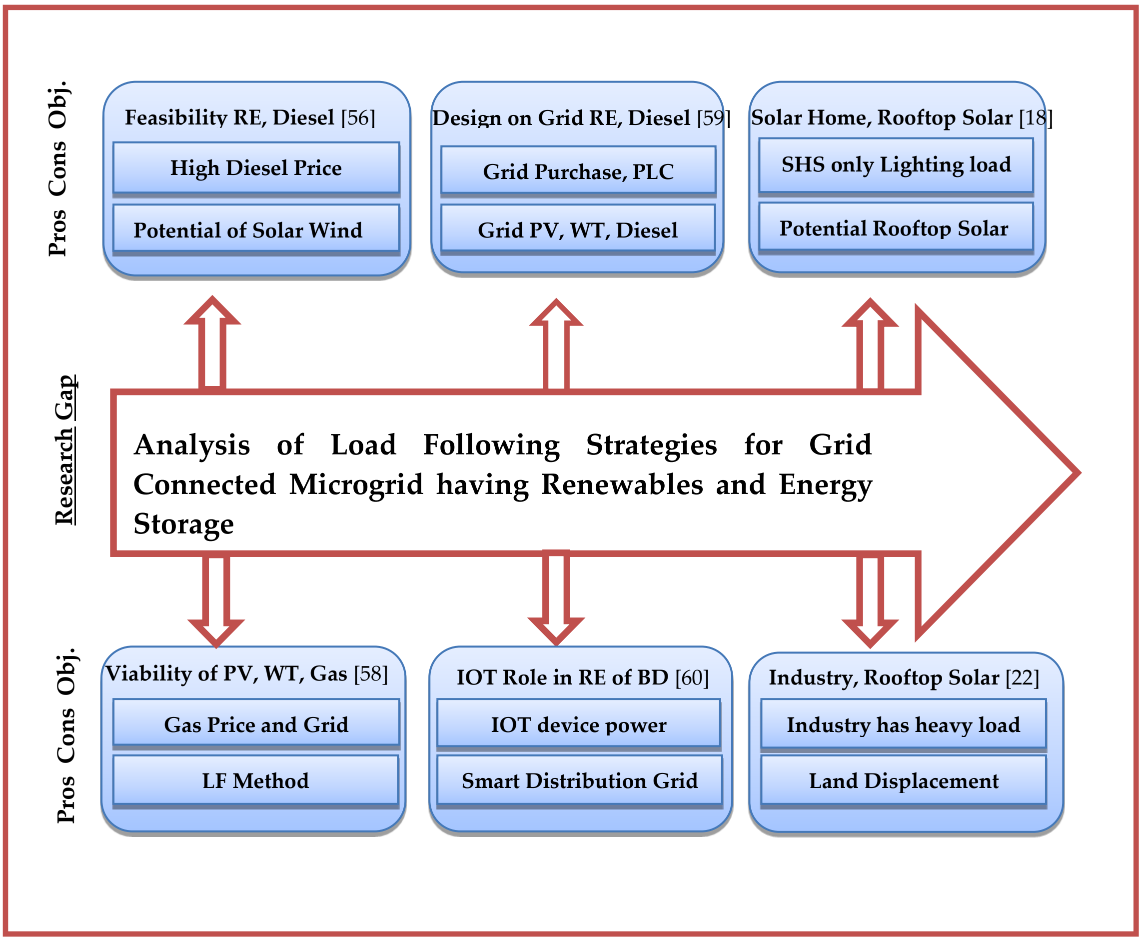


Fig. 2.1 A research gap is identified by evaluating a few significant studies of microgrid.

other configurations [56].

Podder et al. evaluated the size minimization and financial assessment of the PV-WT hybrid electricity generation unit at Patenga, Chattogram to satisfy the power consumption of 276 kWh/d with a maximum load of 40kW. According to the analysis, considering a load that has an 8% yearly capacity deficit an optimal PV-WT-BES hybrid arrangement is more economical than a WT solo arrangement, a PV solo arrangement, or a WT-PV combo arrangement [57].

Atiqur et al. [58], considered a PV (20kW), WT (80kW), Gas (45kW), and BES (245kWh) combo setup a viable option. Taken into account, an isolated region with 100 households load of 213kWh/d. Gas is utilized to create electricity when no green energy is accessible because diesel is so expensive. According to the analysis, the suggested setup is cheaper and more feasible than an additional 33 kV or 11 kV grid connection.

Kabir et al. [59], considered a grid-tied setup for the utilization of two sources of clean electricity (PV and WT) along with a traditional energy source, such as diesel. Absent of a PLC supervisor, the start-up LCOE is around $ 0.16. Then, utilizing the PLC supervisor, the LCOE decreased by $ 0.12 while also decreasing the amount of diesel use, assisting in the development of a sustainable system. The authors encourage and give some statistical data about the potential of renewable resources in Bangladesh [6][5], though they did not include any feasible model and overestimated the renewable energy potential.

Talut et al. estimated that around 11 TWh of electricity can be produced if the rooftop of industry is used for the solar panel but the industry itself has a heavy load so they may not be interested in using rooftop as solar PV need additional maintenance and it may be unstable the grid [22]. Shahriar et al. in, at Monpura Isle, Bhola, suggested a prototype for integrating WT with a PV microgrid [30]. The financial model and infrastructure for the incorporation of the prototype were examined by the author but generated power transmission and distribution are the main challenge as no transmission line directly connected to the island.

Sazzad et al. stated that Solar Home System (SHS) is now possible to supply PV energy to a large number of Bangladeshis living in rural areas [18]. Though SHS is suitable for serving lighting load generally. As rural people's demand for using electric appliances like as TV, Fridges, Water Pumps etc. is rising day by day so SHS cannot satisfy consumer requirements near future. Siddique et al. [60], explored the use of IoT to create an intelligent grid using RE and proposed an IoT-based smart grid model. IoT devices with no rechargeable battery could be a great concerning issue and incorporating IoT devices may not be economically feasible [60]. The authors also did not mention any dispatch strategy for the smart grid optimization. But we have considered load following method as an optimal dispatch strategy and the proposed grid-connected microgrid can serve the local community load smoothly.

In this chapter, I have discussed the present state of a problem for renewable energy growth in Bangladesh. Several solar initiatives like Solar Home Systems, Solar Irrigation Programs etc. were taken but most of them were not successful. Recent research showed Bangladesh has a good potential for wind especially north and South Western regions. Deploying solar PV and windmills in coastal areas could be a viable choice. Several notable pilot projects conducted in various regions discussed in this section. Besides, I have reviewed a few upcoming projects in Bangladesh. In section 2.1.2, the renewable energy trend between BD and the global perspective has been compared. In the previous work section, I reviewed several previous research works and found that there is a research gap in selecting an appropriate load dispatch technique for grid-connected microgrids. Consequently proposed microgrid focused on load following strategies.

3 Research Methodology

This chapter of the thesis describes how I intend to conduct this research. Section 3.1 concisely outlines the core components and layout of the recommended microgrid. Mathematical expressions and theoretical explanations are provided for the necessary components that include photovoltaic cells, windmills, electric load, electrical grid network, converter and the BES. Several dispatch control strategies are briefly discussed in section 3.2. Among them, LF control strategies are applied in the proposed microgrid. LF is considered the optimal strategy as it has a significant effect on most RE resources.

Section ***Error! Reference source not found.*** *discusses various electrical terms that are determined with mathematical expressions. Through equations, electrical terms such as total load served, excess and unmet load and unmet electric load are simply explained. Financial analysis is a vital part of any project, and proper cost calculation can attract investors. Section 3.4 covers the mathematical equation of the microgrid financial forecasting components, such as annualized cost, operating cost, and LCOE, in summary.*

3.1 DESIGING OF THE PROPOSED MICROGRID

A PV, WT, AC/DC converter, AC and DC Bus, Battery storage unit, Load profile, Deferrable load, and the electrical grid interface constitute the simulated microgrid. An illustration of it, which has a rated capacity of 1.3 MWp, is shown

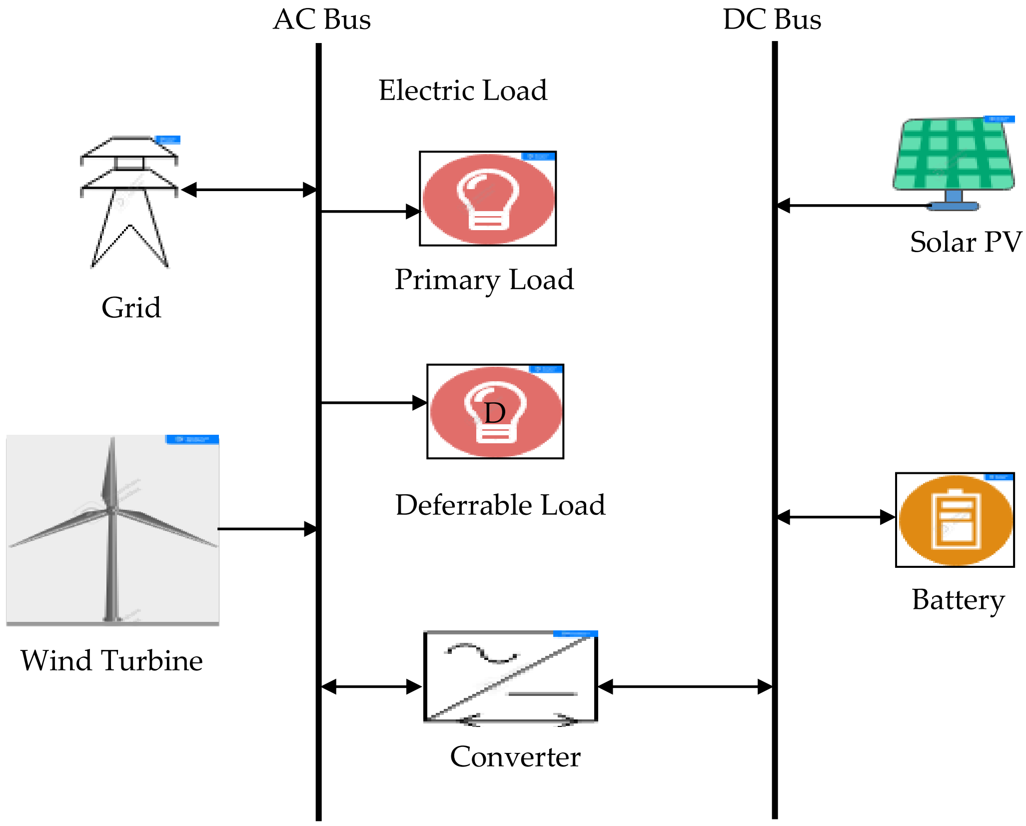


Fig. 3.1 An illustration of the proposed microgrid architecture.

in Fig. 3.1. DC power is supplied by photovoltaic cells and battery backup unit, so it is then converted to AC and coupled to the AC buses via converters. [61]

Electric Grid interface and Windmill, on the contrary, are attached straight to the AC bus. As a result, it may deliver power to the AC loads, while the DC bus could satisfy the requirements of the DC loads attached to it. It is located at GMPX+39 Sultana Mondir, Sitakunda, Chattogram, Bangladesh (22°32.1'N, 91°41.9'E).

Table 3.1 Proposed System Configuration

Element	Tag	Size	Unit
PV	Generic flat plate PV	30.0	kW
BES	Iron Edison LFP 3500Ah	1	strings

WT	Eocycle EO25 Class IIA	4	Nos.
Converter	System Converter	30	kW
Grid	Electric Grid Interface	10	kW
Dispatch strategy	HOMER Load Following		

3.1.1 Solar PV

BD possesses around 6,250 km² of accessible area where utility size PV may possibly generate 156 GW of electricity from the sun [9]. The regular mean sun radiation ranges from 4.3 to 4.9 kWh/m². The Chittagong district of the country is likely suggested as having the greatest possibility for the usage of solar power according to the irradiation chart [6]. Numerous initiatives, including SHS, rooftop PV, PV mini-grid programs, and PV irrigation programs, are currently being undertaken by BPDB and IDCOL [18]. According to the data taken into account, PV is being used at 30 kW of installed capacity. It mounted at user default slope of 22.54°. Calculation for it given below in Fig. 3.2.

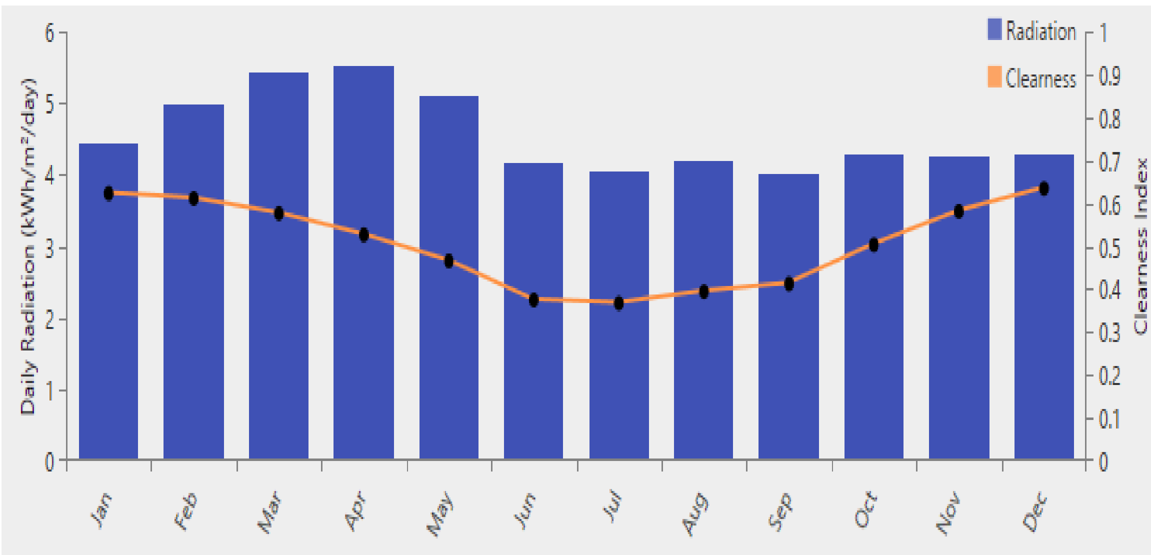
3.1.1.1 PV Array Output Power

The equation given below, which is given in [46], is applied to determine the PV output:

$$P_{PV} = Y_{PV}\, f_{PV} \left(\frac{\overline{G_T}}{\overline{G}_{T,\ STC}}\right)\left[1 + \alpha_P\left(T_c - T_{c,STC}\right)\right] \tag{3.1}$$

whither:

Y_{PV} = installed rating of PV [kW]
f_{PV} = PV derating cofactor [%]
$\overline{G_T}$ = solar emission event on PV [kW/m²]



$\overline{G}_{T,\ STC}$	=event of emission at standard examination situations [1 kW/m^2]
α_P	= temperature coefficient of PV output [%/°C]
T_c	= PV cell temperature [°C]
$T_{c,STC}$	= PV cell temperature under standard examination situations [25°C]

Fig. 3.2 Average solar horizontal irradiance data at proposed site

The previous formula has been condensed since it assumes that the temperature-based power component is zero, hence neglecting the thermal influence on the PV:

$$P_{PV} = Y_{PV}\, f_{PV}\left(\frac{\overline{G_T}}{\overline{G}_{T,\ STC}}\right) \quad (3.2)$$

3.1.1.2 PV derating factor

The derating factor (f_{PV}) is a parameter used to adjust for lower output in actual operating environments compared to the ideal circumstances when the photovoltaic panel was rated. It is an important component for photovoltaic panels since it represents the efficiency of the module. It takes into consideration elements such as surface soiling, weather, wire losses, aging, and so on. This factor value is normally provided in the manufacturer's datasheet.

Masrur et al. at first in [62], put solar panel power loss to 12%, resulting in a derating factor that was 0.88, which corresponds to the PV supplier's claim. The polycrystalline silicon modules derating factor from the manufacturer's specified datasheet was 0.97 (as determined during factory testing) [63]. Jordan et al. in [64], found that derating factor ranges from 0.5% to 0.8% for a crystalline Si-based PV throughout the year. Taking into account these several research and according to Homer generic PV data derating factor of the proposed microgrid is determined as 0.8.

3.1.1.3 The PV incident radiation

The calculation procedure described in [65] is employed to calculate the solar declination:

$$\boldsymbol{\delta = 23.45° sin\left(360° \frac{284+n}{365}\right)} \quad (3.3)$$

whither, $\boldsymbol{n}$= the day of the year

An hour angle can be determined as the period of a day that stimulates the position of the sun on the horizon. The hour angle is calculated using the formula below, which is found in [65]:

$$\boldsymbol{\omega = (t_s - 12hr).15°/hr} \quad (3.4)$$

whither, t_s= the solar time [hr]

$\boldsymbol{t_s}$**,** has a period of 12 hours at sunrise and 13 hours and 35 minutes after that. The assumption behind the aforementioned calculation is that the sunlight travels around the sky at a rate of 15 degrees every hour. It is possible to calculate the angle of incidence for any surface direction by applying the corresponding equation given in [65]:

$$\boldsymbol{cos\theta = sin\delta sin\emptyset cos\beta - sin\delta cos\emptyset sin\beta cos\gamma + cos\delta cos\phi cos\beta cos\omega + cos\delta sin\phi sin\beta cos\gamma cos\omega + cos\delta sin\beta sin\gamma sin\omega} \quad (3.5)$$

whither:

$\boldsymbol{\theta}$ = incidence angle [°]

$\boldsymbol{\beta}$ = surface slope [°]

γ = surface azimuth [°]

$\boldsymbol{\phi}$ = latitude [°]

$\boldsymbol{\delta}$ = heliacal declination [°]

$\boldsymbol{\omega}$= hour angle [°]

The zenith angle, or the angle across a vertical line and the line to the direct sun, is an especially significant incidence angle ($\boldsymbol{\theta}$). When the sun is straight above the ground, the zenith angle has a value of zero, whereas if the sun appears on the skyline, the value is ninety degrees. Since a horizontal plane has an angle of zero, it can derive the zenith angle formula by changing $\boldsymbol{\beta = 0°}$ in the preceding formula, which results given in [58] below:

$$\boldsymbol{cos\theta_z = cos\phi cos\delta cos\omega + sin\phi sin\delta} \tag{3.6}$$

where, $\boldsymbol{\theta_z}$ = the zenith angle [°]

The angle formed by the light from the sun and its vertical trajectory is known as the solar zenith angle. It is the opposite of solar height, which is referred to as sun altitude. The ratio of surface to interplanetary emission calculates the clearness factor. It can be calculated by the formula given in [66], [67]:

$$\boldsymbol{k_T = \frac{\bar{G}}{\overline{G_O}}} \tag{3.7}$$

whither:

$\boldsymbol{\bar{G}}$ = world horizontal emission [kW/m2]

$\boldsymbol{\overline{G_O}}$ = interplanetary horizontal emission [kW/m2]

The entire quantity of shortwave energy encountered above on a surface horizontal to the earth is referred to as global horizontal irradiance ($\boldsymbol{\bar{G}}$). The strength (intensity) of sunlight that exists at the surface of the environment of the planet is known as extraterrestrial radiation ($\boldsymbol{\overline{G_O}}$). On a trajectory perpendicular to sunlight, it is typically stated in irradiance units (Watts per square meter). The total of the beam and diffuse solar radiation equals planetary solar radiation; this correlation can be expressed by the formula given in [68]:

$$\boldsymbol{\bar{G} = \overline{G_b} + \overline{G_d}} \tag{3.8}$$

whereas:

$\boldsymbol{\overline{G_b}}$ = beam radiation [kW/m2]

$\boldsymbol{\overline{G_d}}$ = diffuse radiation [kW/m2]

On the ground of the planet, some of the solar radiation is known as beam radiation ($\overline{G_b}$), which is solar radiation that does not undergo scattering by the environment as it moves from the sun to the planet's ground. The effect of a shadow is formed by beam radiation, also known as direct radiation. The sky is filled with diffuse radiation ($\overline{G_d}$), which does not create a shadow.

HDKR model can be applied to determine the planetary solar radiation striking the PV array's inclined surface. Before using this model, three additional elements should be identified. The expression below determines **R_b,** or the proportion of beam emission on an inclined surface to beam emission:

$$\boldsymbol{R_b = \frac{cos\theta}{cos\theta_z}} \tag{3.9}$$

The beam radiation transmittance through the atmosphere is measured by the anisotropy index, abbreviated Ai. This ratio can be applied to calculate the quantity of circumsolar diffuse emission, additionally referred to as onward scattered emission. The following equation yields the anisotropy index:

$$\boldsymbol{A_i = \frac{\bar{G}_b}{\bar{G}_o}} \tag{3.10}$$

In the end, it needs to identify a variable that is employed to explain the occurrence where greater amounts of emission originate near the horizon compared to the remainder through the sky. This parameter is determined by the next formula and is connected to cloudiness:

$$\boldsymbol{f = \sqrt{\frac{\bar{G}_b}{\bar{G}}}} \tag{3.11}$$

The HDKR approach uses the next formula from [69] to calculate the universal emission incidence over the PV:

$$\boldsymbol{\bar{G}_T = (\bar{G}_b + \bar{G}_d A_I)R_b + \bar{G}_d(1 - A_I)\left(\frac{1+cos\beta}{2}\right)\left[1 + f sin^3\left(\frac{\beta}{2}\right)\right] + \bar{G}\rho_g\left(\frac{1-cos\beta}{2}\right)} \tag{3.12}$$

whither: ρ_g = surface reflectance

The percentage of solar energy that strikes the earth's surface and is reflected is known as the ground reflectance (ρ_g). The radiation penetration on the angled solar cells is determined using this measurement, however, its impact is minimal. Equation 3.12 has been headed for define the PV power output and cell temperature.

3.1.2 Wind Turbine

The velocity of the winds is an important factor in determining whether or not a windmill may be erected at the chosen location. The mean wind velocity at Sitakunda is roughly 4.02m/s, as shown in Fig. 3.3. It is obtained at the centre of the hub level using the formulas presented in [46], [70]:

$$\boldsymbol{U_{hub}} = \boldsymbol{U_{anem}} \cdot \frac{\ln(Z_{hub}/Z_0)}{\ln(Z_{anem}/Z_0)} \tag{3.13}$$

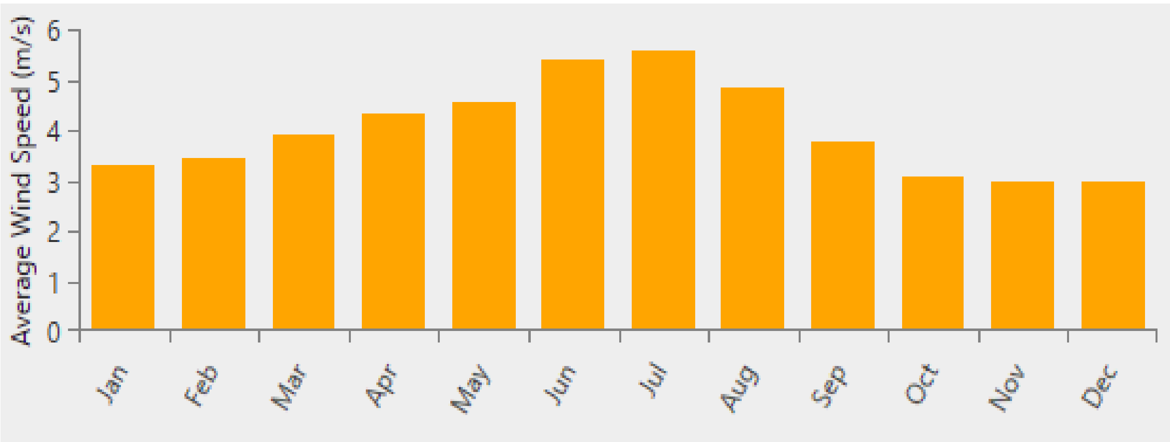
whither:

U_{hub} = breeze velocity at hub level [m/s]

U_{anem} = breeze velocity at aerometer level [m/s]

Z_{hub} = WT hub level [m]

Z_{anem} = aerometer tallness [m]



Z_0 = base unevenness size [m]

Fig. 3.3 Typical breeze velocity at the recommended location

An instrument used to monitor air pressure and velocity is called an anemometer or aerometer. When studying variations in the weather, scientists use anemometers. If the principle of the power law is utilized, the next formula is employed in [70] to calculate the hub level wind velocity:

$$\boldsymbol{U_{hub}} = \boldsymbol{U_{anem}} \cdot \left(\frac{\boldsymbol{Z_{hub}}}{\boldsymbol{Z_{anem}}}\right)^{\boldsymbol{\alpha}} \tag{3.14}$$

whither, $\boldsymbol{\alpha}$ = power rule exponent

In this thesis, Eocycle EO25IIA vertical wind turbine model is considered. Its nominal capacity is 25 kW per unit and $50,000 of capital cost as per data sheet. Power graph of it given in below Fig. 3.4. Power graphs generally indicate WT efficiency at nominal pressure and temperature. For compensation of actual scenarios, multiply the anticipated power production with the power graph with the wind density ratio as given in [46], [71], [72]:

$$\boldsymbol{P_{WTG}} = \left(\frac{\boldsymbol{\rho}}{\boldsymbol{\rho_0}}\right) . \boldsymbol{P_{WTG,STP}} \tag{3.15}$$

whither:

$\boldsymbol{P_{WTG}}$ = WT power production [kW]

$\boldsymbol{P_{WTG,STP}}$ =WT output at ideal pressure and temperature [kW]

$\boldsymbol{\rho}$ = actual wind density [kg/m^3]

$\boldsymbol{\rho_0}$ = wind density at ideal pressure and temperature[1.22kg/m^3]

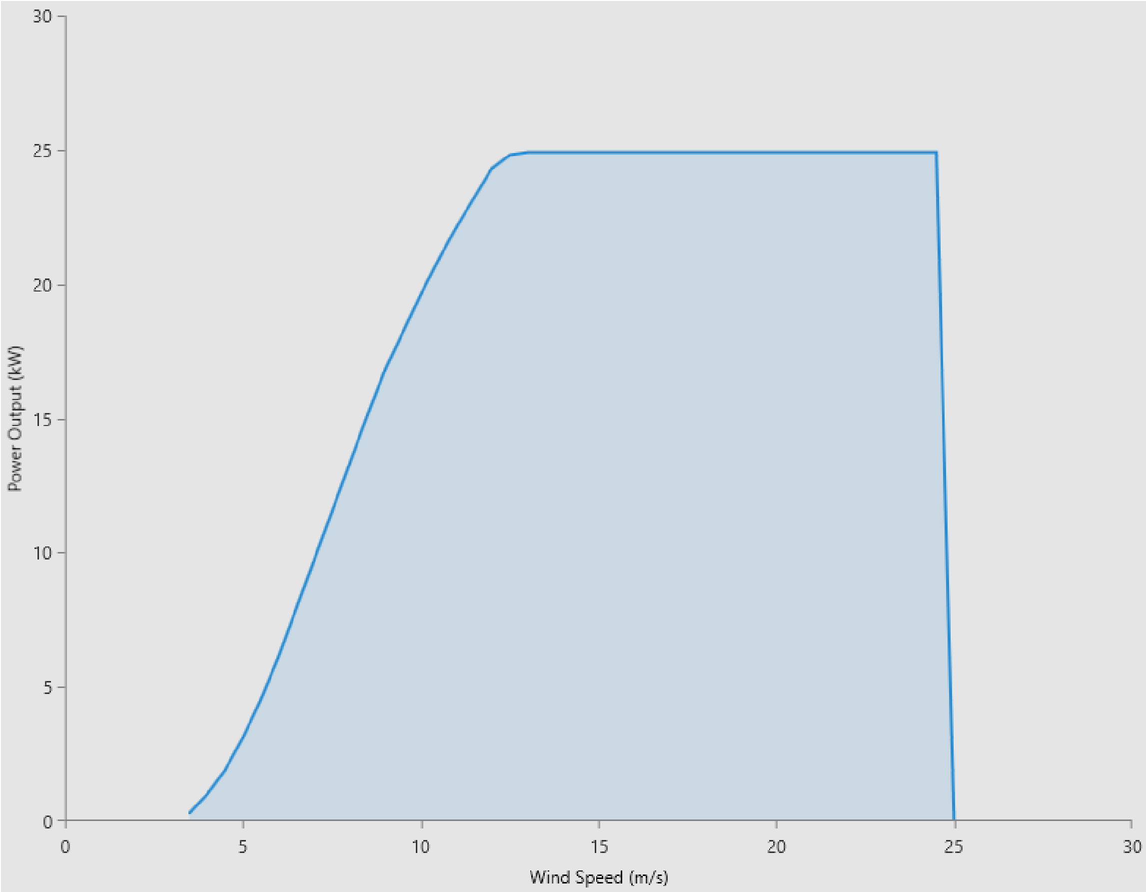


Fig. 3.4 Power Curve of WT model

3.1.3 Electric Load

For the microgrid, a total scaled yearly average load demand of 165.59 kWh/day has been taken into account. July is considered as the peak month in accordance with BD weather, peak load considered 23.62 kW with load factor of 0.29. Taking into account a community in the suggested locations, the load comprises of AC forms of loads. Scaled data are used in the calculations. Each baseline data value is divided by a common factor to generate scaled data, which generates a yearly mean amount that matches the amount specified in the scaled yearly mean.

3.1.3.1 Primary Load

It is the demand that should instantly satisfy so as to prevent an unmet load is known as the primary load. The system tries to satisfy it in all-time step. In Fig. 3.5, the monthly average primary load demand depicted.

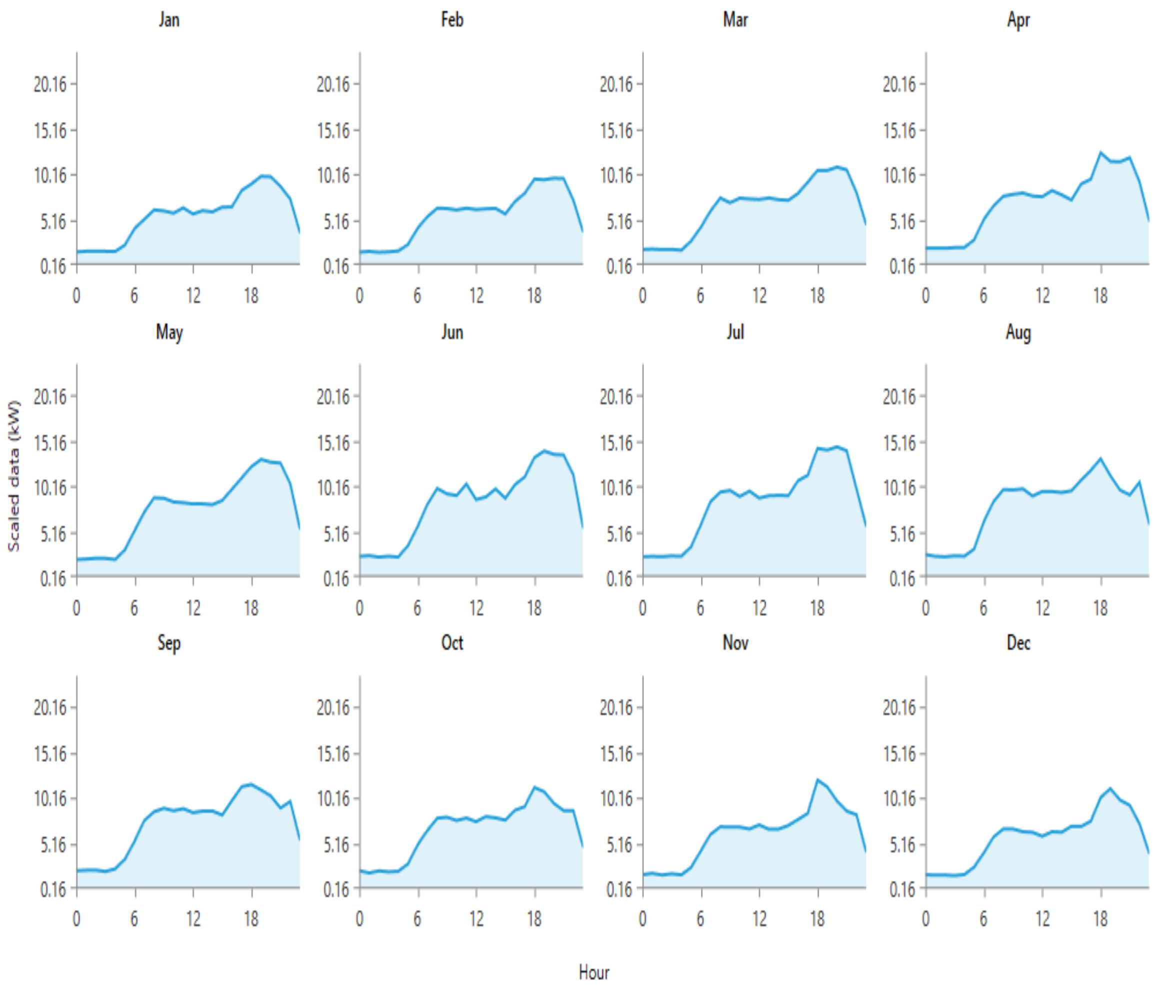


Fig. 3.5 Scaled Monthly Typical Primary Load Demand

3.1.3.2 Deferrable Load

Deferrable load is able to delayed until power becomes accessible however still demands a specific amount of energy to operate in a specific amount of period. Loads are frequently classified as deferrable if they are attached to BES [73]. A common case is the circulation of water, where users have substantial freedom in the timing of the pump's operation if the water tank is not fully dry. Creating ice and rechargeable storage are two more cases. The microgrid's normalized yearly mean deferrable load requirement is 12.5 kWh/d and 16 kW of highest consumption. The initial deferrable load demand data is scaled for use in computations. The initial data sets have been modified using one of the 12 initial values, leading to a yearly mean quantity that equals the value that is selected in scaled yearly mean.

Following the initial consumption however prior to recharging the BES is the deferrable load [10]. Under the LF, it will be supplied solely if the unit generates surplus electricity or if the storage container gets dry. Whenever a generator is operational and able to provide additional energy than is necessary to meet the initial demand, the deferrable demand also receives power under the cycle charging method.

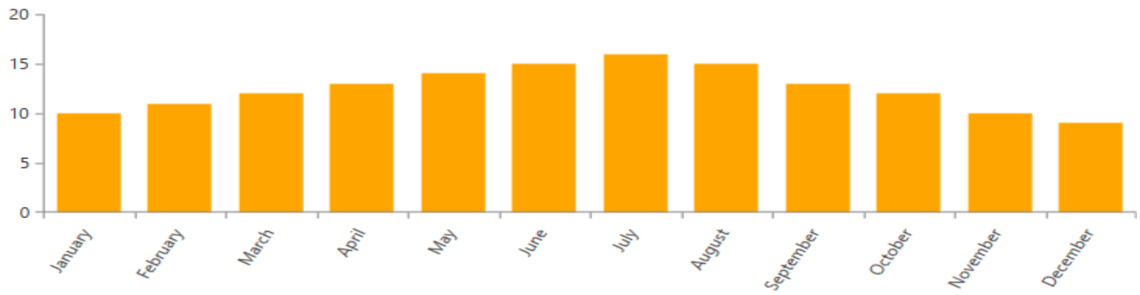


Fig. 3.6 Monthly Average Deferrable Load

Despite the dispatch technique, the highest deferrable demand is treated as an initial load if the storage reservoir level approaches nil. Finally, utilize as much of the highest deferred consumption as can be met by the dispatchable resources like as BES, or the power grid etc.

3.1.4 Energy Storage

An Iron Edison LFP 3500Ah battery model is used as the energy storage. It has 168kWh of nominal capacity, 48V_{dc} of nominal voltage, 1000A of peak charge and discharge current.

3.1.4.1 Maximum Battery Charge Power

The entire quantity of energy that the two tanks can hold is known as the peak storage capacity. The maximum charging power of the storage is restricted in three ways. The kinetic storage method in [46], [74] is the basis of the first constraint. Equation 3.16 provides the maximum power obtainable by the two-tank system:

$$P_{batt,amax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \qquad (3.16)$$

where:

Q_1 = amount of energy [kWh] in the BES
Q = overall quantity of energy in the BES [kWh]
c = storage capacity ratio
k = storage rate constant [h-1]
Δt = span of the period [h]

The dimension of the energy tank that is available to the total dimension of both tanks is represented by the capacity ratio (c). The rate constant (k) is proportional to the conductance among the two tanks and so determines how rapidly the battery can transform confined energy to accessible energy or vice versa. The following constraint relates to the maximum charge rate of the storage. Its recharge power associated with the optimum charge percentage is provided by the subsequent formula given in [46] ,[75], [76]:

$$P_{batt,amax,mar} = \frac{\left(1 - e^{-\alpha_c \Delta t}\right)\left(Q_{max} - Q\right)}{\Delta t} \qquad (3.17)$$

whither:

α_c = BES optimum charge percentage [A/Ah]
Q_{max} = cumulative capacity of BES [kWh]

The final constraint deals with the optimum recharge current for the BES Component. The optimum recharge power for it is given by the subsequent formula:

$$P_{batt,amax,mcc} = \frac{N_{ban} I_{max} V_{nom}}{1000} \qquad (3.18)$$

whither:

N_{batt} = quantity of batteries
I_{max} = peak recharge current [A]
V_{nom} = rated voltage [V]

The optimum charge power will be the same as the most minimal of these constraints if all are applicable soon after charging losses:

$$P_{batt,cmax} = \frac{MIN(P_{batt,cmax,kbm}, P_{batt,cmax,mar}, P_{batt,cmax,mcc})}{\eta_{batt,c}} \tag{3.19}$$

whither, $\eta_{batt,c}$ = BES charge effectiveness.

3.1.4.2 Maximum Discharge Power

The next formula estimates the optimum quantity of power that the BES is able to release over a particular amount of time as given in [46], [77] :

$$P_{batt,dmax,kbm} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + Qkc(1 - e^{-k\Delta t})}{1 - e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{3.20}$$

The subsequent formula, which is provided in [46], [74] is used to compute the optimum discharge power:

$$P_{batt,dmax} = \eta_{batt,d} P_{batt,dmax,kdm} \tag{3.21}$$

3.1.5 Converter

Converters are employed to transform AC to DC or the opposite. To cope with both types of loads, the system that is recommended in **Error! Reference source not found.** displays a hybrid network with both AC and DC buses. In contrast, generation units generate both DC (i.e., solar PV) and AC (i.e., Grid, WT), and storage devices store DC (i.e., battery). Therefore, the recommended microgrid converter's efficient performance is essential to the entire network.

3.1.6 Grid Model

This microgrid is linked to the national grid, permitting surplus energy to be directly exported and unsatisfied demands to be fulfilled by the grid. In Simple Rates mode, it is possible to define an unchanged electricity fee and a sell-back rate. Simple Rates features two tabs: Parameters, which includes rates and net metering options, and Emissions, which includes several types of emissions percentages. The net purchase from the grid will be determined monthly. Grid electricity is bought at 0.059 dollars per kWh, and it can be exported for 0.070 dollars per kWh. As GOB wants to promote renewable energy and microgrids so the power sale rate to the grid is a little bit higher.

3.2 EXPLANATION OF DISPATCH STRATEGIES

The method of regulation incorporates several kinds of dispatch algorithms in a microgrid architecture that are dependent on load requirement, power producing unit, and the environment [1], [78]. "When RE is not enough to meet the demand, a dispatch strategy is employed to regulate the activity of the generating unit and BES" [79], [80]. The microgrid configuration could use one of five methods:

(i) LF

(ii) CC

(iii) GO

(iv) CD

(v) PS

According to LF, generators deliver only sufficient power to fulfil the load demand. The load requirement would have been satisfied by RE in order to maintain the network stable and profitable [81]. Additionally, Oladigbolu et al. in [82], evaluated the feasibility of HRES paired with a solo generator in an isolated region of Nigeria by applying the LF.

The generator must always run at its peak potential according to the CC method. The BES is being charged using the surplus generator energy. The ideal environments for CC are those with little or no RE sources. In [83], the authors compared strategies for constructing a HRES with a comparatively elevated load factor with the aim of providing some research findings in Indonesia. They concluded that the CC technique worked better to their particular setup. In the GO method, generator arrangements are used in a specified order to satisfy a load requirement demand which encounters the effective capacity in the foremost place [84].

According to CD, prediction of future net load demand is excluded. Based on the present net load demand estimations, it decides when to use a generator to recharge the BES. While the electrical demand is inadequate, it stays away from operating a generator [84], [85]. In every stage, it picks the cheapest option of LF or CC. While the net demand is inadequate, the CD control strategy employs the CC procedure; whenever the net demand is large, it employs the LF procedure. [86]. Future RE supply accessibility and the anticipated demand for thermal and electricity consumption have been determined or anticipated in the PS strategy. As a consequence, through its use, the system's overall running expenditure will be able to decrease [1].

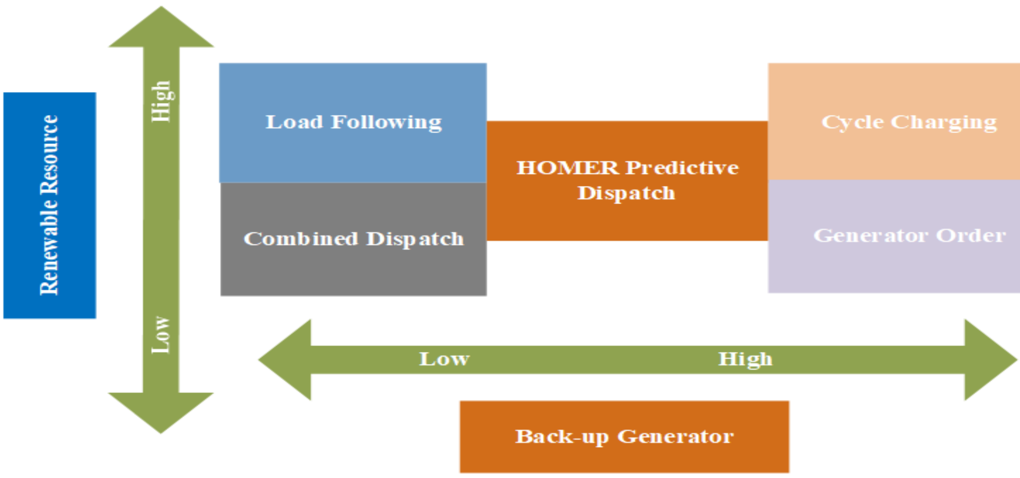


Fig. 3.7 The impact of dispatch strategies on renewable sources and backup

In an island microgrid, dispatch strategies provide guidelines for managing electricity and determining the best size requirements. The utilization of the diesel generator backup in emergency situations, when renewable resources are not available or when load demand changes abruptly is crucial for all five dispatch systems. For the available dispatch options, Fig. 3.7 below depicts the influence of RE and generator backup for the production of electricity, and it also indicates the importance of the operational schedule [87]. The GO encounters the greatest effect over the backup generators, whereas the LF method encounters the greatest effect over the RE, according to the study and findings. LF becomes the optimal method if the amount of RE is large, whereas GO becomes the optimal if the amount of RE is limited, as shown in Fig. 3.7 [87]. Only LF and CC can operate on the grid of the five dispatch strategies. The CD, GO, and PS system architectures are only for off-grid use.

A general comparison between LF and CC strategies given below:

- Load Following
    - Less battery throughput
    - More headroom for renewables
    - High renewable penetration systems
    - More generator runtime and start/stop
- Cycle Charging
    - Keep the mean level of charge greater.
    - Additional fuel is needed.
    - Decreased battery lifespan and higher energy throughput
    - System with a smaller RE injection

So, after analysing the comparison between LF and CC, it is clear that LF could be the best dispatch strategy for microgrids containing renewables.

3.2.1 Load Following Strategies (LF)

The LF is employed to maximize the feeding of RE. The BES is only able to be recharged using surplus RE, like as WT and PV [88]. It prevents the generator or grid interface from recharging the BES. The generator generates only sufficient electricity to handle the unfulfilled demand as a result.

The procedure governing it is shown in Fig. 3.8 [27]. The WT and PV arrangement has been designed to supply the necessary demand. When the state of charge (SoC) is under 100 percent ($P_C > 0$), the surplus power is going to be employed for charging the BES if the net necessary load ($Pnet$) is minus, indicating surplus power. Nevertheless, the BES will allow discharge when the net required load demand is above zero ($P_{net} > 0$), the amount of energy remains within the BES ($P_D > 0$), and COE of the BES is lower compared to COE of operating the grid interface or generator without refilling the BES ($C_{bat}\ C_{gen}\ (at\ P_C = 0)$). If not, a generator or grid interface is going to be utilized to satisfy the residual demand.

Due to the characteristics of the method, it is frequently appropriate for plants who's RE output throughout the day exceeds the amount of load needed. It predicts that the grid power will be required in the next high demand times [27]. In order to conserve money at the moment, grid power is not required to recharge the BES. On the other hand, it becomes ineffective if the grid power imported continuously at low load for an extended period of time [27].

3.3 DETERMINING VARIOUS ELECTRICAL OUTPUTS

3.3.1 Total Load demand Served

The overall load demand is the cumulative of the energy consumed in a year to satisfy both primary and deferrable demands as well as the energy exported. It stated in [46] estimated using the formula provided below:

$$E_{served} = E_{served,AC_{prim}} + E_{served,DC_{prim}} + E_{served,def} + E_{served,sales} \tag{3.22}$$

whither:

$E_{served,primAC}$ = AC demand satisfied [kWh/year]

$E_{served,primDC}$ = DC demand satisfied [kWh/year]
$E_{served,def}$ = deferrable demand satisfied [kWh/year]
$E_{grid,sales}$ = energy exported [kWh/year]

3.3.2 Excess and Shortage

3.3.2.1 Excess Electricity

Surplus electricity that needs to be evacuated as it is unable to be utilized to charge BES or serve a load. It happens if the batteries fail to consume the surplus power. The surplus electricity proportion is defined as the sum of all surplus electricity divided by overall generation. The next equation is employed to define this amount as given in [46]:

$$f_{excess} = \frac{E_{excess}}{E_{prod}} \tag{3.23}$$

whither:

E_{excess} = overall surplus energy [kWh/yr]
E_{prod} = overall electric generation [kWh/yr]

3.3.2.2 Unmet Load

A demand for energy that the electrical system has no ability to satisfy can be referred to as an unmet load. It happens when there is more demand than supply for electricity. The unmet load portion represents the proportion of the entire yearly demand for power that has not been met due to inadequate production. Below equation is given for unmet load fraction:

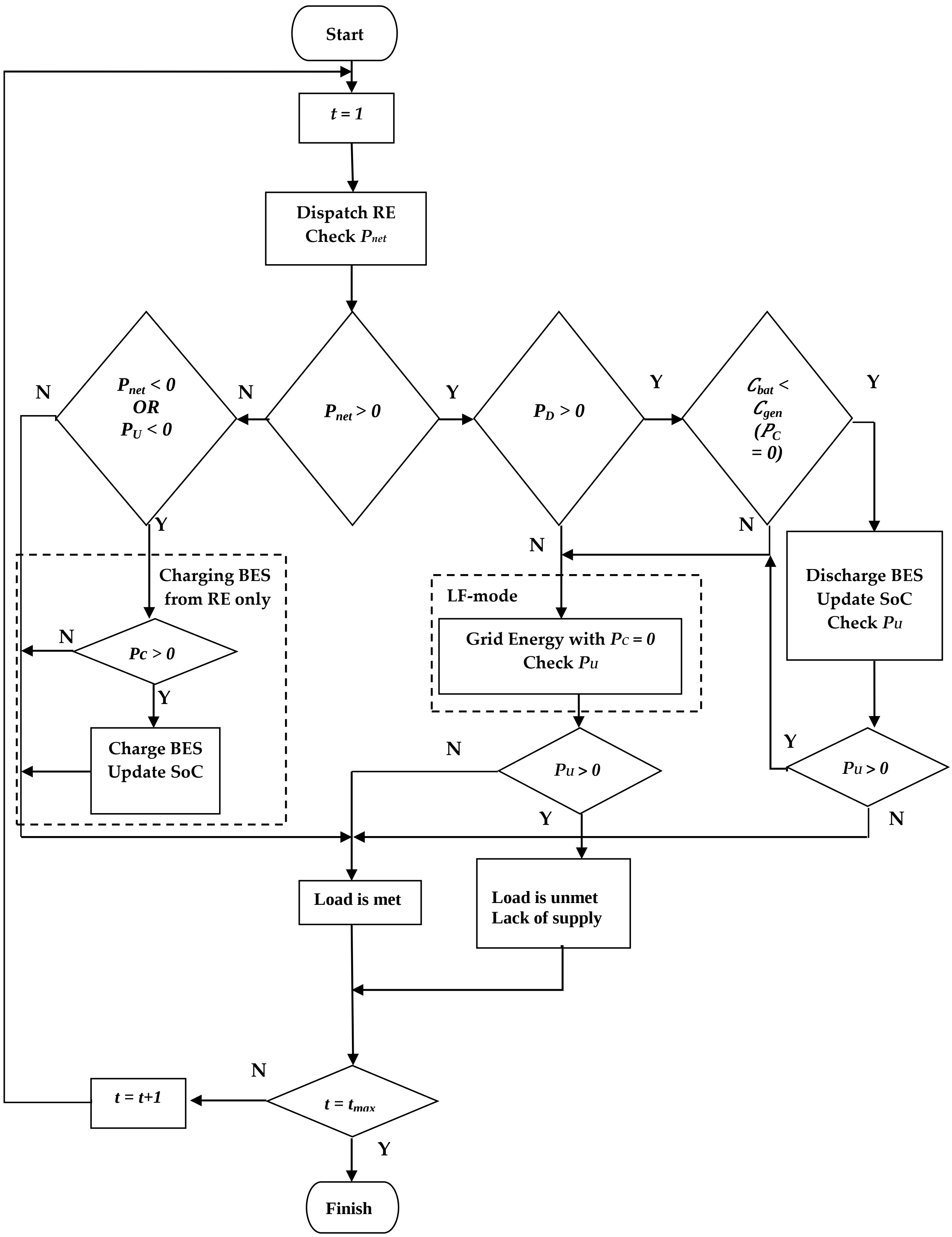


Fig. 3.8 Flowchart of Load Following (LF) strategies

$$f_{unmet} = \frac{E_{unmet}}{E_{demand}} \tag{3.24}$$

whither:

E_{unmet} = overall unmet demand [kWh/year]

E_{demand} = overall yearly electric load [kWh/year]

3.3.3 Renewable Fraction

The volume of electricity supplied to meet the demand that came from RE is referred to as the renewable portion. The below formula is for calculating it as given in [46]:

$$f_{ren} = 1 - \frac{E_{nonren}+H_{nonren}}{E_{served}+H_{served}} \tag{3.25}$$

whither:

E_{nonren} = non-RE generation [kWh/year]

$E_{grid,sales}$ = energy imported [kWh/year]

H_{nonren} = non-RE thermal generation [kWh/year]

E_{served} = overall electrical demand satisfied [kWh/year]

H_{served} = overall thermal demand satisfied [kWh/year]

3.4 DETERMINING VITAL PARAMETER OF FINANCIAL ANALYSIS

3.4.1 Annualized Cost

The annualized expenditure can be obtained initially by determining the NPC and afterward multiplying with CRF stated in the next formula as given in [46].

$$C_{ann} = CRF\left(i, R_{proj}\right).C_{NPC} \tag{3.26}$$

whither:

C_{NPC} = NPC [$]

i =yearly actual rebate amount [%]

R_{proj} = project time [year]

CRF() = a function recurring the CRF

To estimate the difference between one-time expenses and annualized costs, it needs to employ the real discount rate (***i***). Equation 3.28 is used to calculate the real discount rate which assumes the inflation of the dollar over the entire project lifetime.

3.4.1.1 *The Net Present Cost*

Net current expenditure is reckoned by deducting the current worth of all the costs related to constructing and upholding the element all over the project from the existing value of every dollar of income it produces during the same time frame. System calculates the NPC of each part of the setup as well as the setup as an entire entity.

3.4.1.2 *The Capital Recovery Factor*

Current worth of an annuity, which consists of a set that has identical yearly currency movements, is calculated using a relation known as CRF. The next equation for it given in [46]:

$$\boldsymbol{CRF(i,N)} = \frac{\boldsymbol{i(1+i)^N}}{\boldsymbol{(1+i)^N-1}} \tag{3.27}$$

whither, i = actual rebate amount
N = years

The variables are evaluated using the actual rebate amount, and the distinction among a single and ongoing expenditure is made. Using it, discount factors are computed from NPC and annualized costs.

$$i = \frac{i'-f}{1+f} \tag{3.28}$$

whither:
i' = nominal discount rate
f = probable inflation amount

3.4.2 Operating Cost

The annualized value of all expenses and income, excluding initial capital costs, is the operating cost. Operating costs are the ongoing expenses incurred every day to carry out a project as planned. The operating expenditure can be obtained from the next formula as given in [46]:

$$C_{operating} = C_{ann,tot} - C_{ann,cap} \tag{3.29}$$

whither:

$C_{ann,tot}$ = overall annualized expenditure [$/yr]
$C_{ann,cap}$ = overall annualized investment [$/year]

3.4.3 Levelized Cost of Energy

The mean price per kWh of electricity that can be used and produced in the microgrid is known as the LCOE as given in [46].

$$LCOE = \frac{C_{ann,tot} - C_{boiler} H_{served}}{E_{served}} \tag{3.30}$$

whither:

$C_{ann,tot}$ = overall annualized expenditure [$/year]
C_{boiler} = boiler fringe charge [$/kWh]
H_{served} = overall thermal demand satisfied [kWh/year]
E_{served} = overall electrical demand satisfied [kWh/year]

In the methodology chapter, the theoretical and mathematical model of all elements of the proposed microgrid has been described. In section 3.11 and section 3.1.2, a mathematical model for solar and wind energy calculation has been described with several equations. The equation for total load served and renewable fraction or penetration calculation stated in section 3.3. In section 3.2, after analysing several dispatch strategies, it is clear that LF could be the best dispatch strategy for microgrids containing renewables. As a part of financial optimization, section 3.4 described several financial components like annualized cost, operating cost, levelized cost of energy etc.

4 Results and Analysis

This research work will mostly focus on several correlated factors. Section 4.1 focuses on the output response of individual components of the proposed microgrid. The summary of system component outputs allows us to determine whether the estimated output response is achievable or not.

As stated in the section ***Error! Reference source not found.****, the LF dispatch strategy directs and forces the system to optimize its application of RE and BES. Deferrable load might shift some load during peak hours, ultimately preventing the start-up of numerous power plants or diesel generators, as described in section* ***Error! Reference source not found.****.*

NPC, capital cost, operating cost etc. are calculated in section ***Error! Reference source not found.*** *which allows us to determine the cost estimation of the planned microgrid project. The projected microgrid's capability to withstand the increase in load with respect to time is verified in section 4.5. Section 0 depicted various time plot for the proposed microgrid response.*

4.1 HOMER PRO SIMULATION OUTPUTS OF THE PROPOSED MICROGRID BY USING THE LF STRATEGIES

4.1.1 Electrical Summary

The system needed 528 kWh per day and could produce 115 kW at its maximum capacity. Fig 4.1 and Table 4.1 summarized the annual power supply from each source. Over 195,133 kWh/yr of energy was produced annually by the proposed microgrid, with energy generated by solar PV accounting for about 43,119 kWh/yr (22.1%), wind energy accounting for about 137,494 kWh/yr (70.5%), and energy bought via the grid interface contributes approximately 14,440 kWh/yr (7.40%).

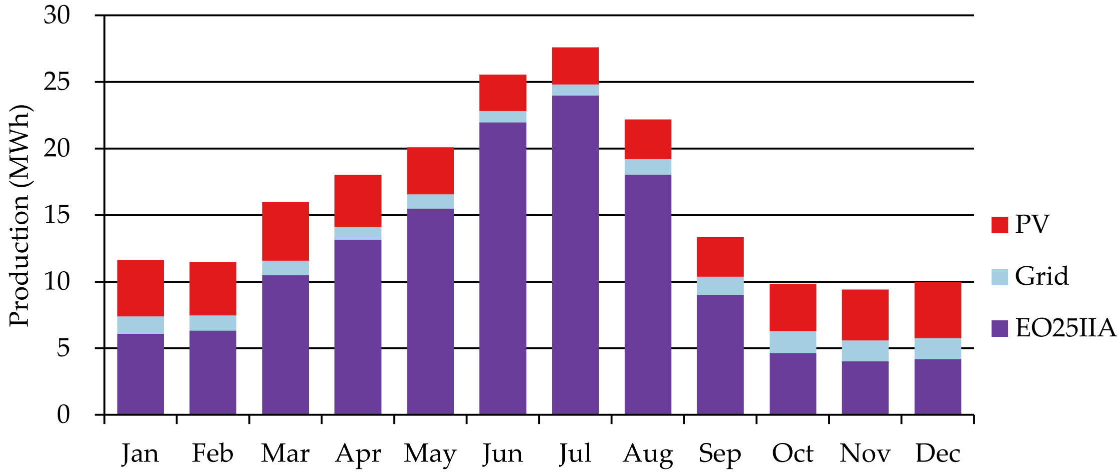


Fig. 4.1 Annual RE Production and Grid Energy Import

Table 4.1 Simulated yearly average output of renewables and grid import

Component	Production (kWh/yr)	Percent
Generic flat plate PV	43,199	22.1
Eocycle EO25 Class IIA	137,494	70.5
Grid Purchases	14,440	7.40
Total	195,133	100

The yearly mean of both deferrable and primary load requirements of 12.50 kWh/day and 165.59 kWh/day had been considered, respectively. Table 4.2, shows that the annual consumption of AC primary load was approximately 60,442 kWh/yr (31.3%) and the annual consumption of deferrable load was approximately 4,564 kWh/yr (2.37%). The remaining generated power sold to the grid and annual grid sales were roughly 127,876 kWh/yr (66.3%). As all excess electricity generated from renewable resources were sold to Grid so system has no excess electricity. Hence, during unmet load microgrid started to purchase electricity from grid so system also had no unmet load and capacity shortage. Though Plant preventive shutdown and unplanned breakdown situation was not considered in this thesis.

Table 4.2 Annual average consumption of electric load and grid export

Module	Consumption (kWh/yr)	Percent
Primary Load	60,442	31.3
DC Load	0	0
Deferrable Load	4,564	2.37
Grid Exports	127,876	66.3
Overall	192,882	100

4.1.2 PV

According to the simulation data shown in Tables 4.3 and Table 4.4, PV's maximum output was roughly 29.8 kW, with a 30kW max rating and a 71.5% injection of PV. Due to the fact that it output is nil at night, the annual operating hours of PV were only 4,372 hrs/yr. Levelized cost of it were roughly 0.197 $/kWh. It had an average daily output of 118 kWh/d and a yearly production of 43,199 kWh/yr and capacity factor of 16.4%.

Table 4.3 Summary of Solar PV penetration and LCOE

Quantity	Value	Units
Peak Generation	29.8	kW
PV Injection	71.5	%
Operating Time	4,372	hrs/yr
LCOE	0.197	$/kWh

Table 4.4 Annual average Solar PV output

Amount	Value	Units
Nominal Rating	30.0	kW
Average Generation	4.93	kW
Average Generation	118	kWh/d
CF	16.4	%
Overall Generation	43,199	kWh/year

A sort of graph that displays time series data over one year is a data map (DMap). The X-axis indicates the 365th day of the year, and the Y-axis specifies the hour of each day. When compared to a normal time series plot, the DMap style frequently makes it easier to understand regular and seasonal shapes. Solar output over a year is depicted in the DMap below Fig. 4.2. It can quickly be seen from the DMap that PV generation declined in the middle of the year and was only produced during the daytime.

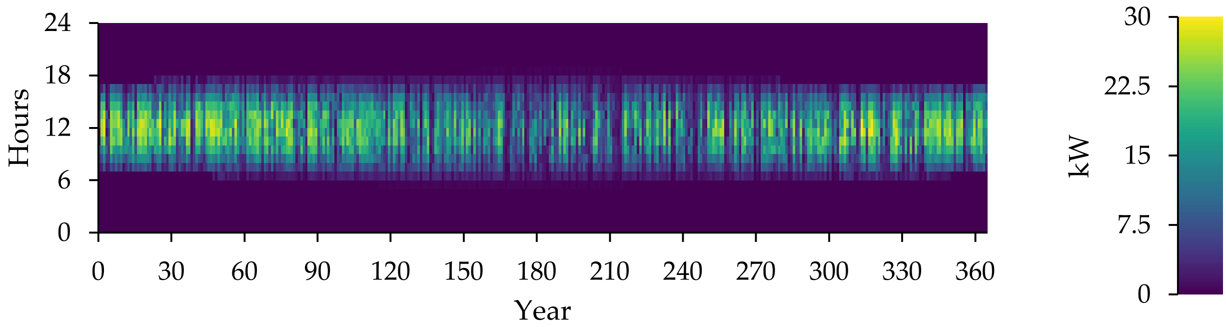


Fig. 4.2 DMap of the PV Output (kW)

4.1.3 Wind Turbine: EO25IIA

The wind is quite important in microgrids worldwide. The wind's overall installed rating was 100 kW, as shown by the information in Tables 4.6 and Table 4.5, with an estimated production of 15.7 kW with a CF of 15.7%. In comparison to solar (0.197 $/kWh), wind had a lower levelized cost (0.145 $/kWh). Overall, 5,593 hrs/yr of time wind turbine was in operation with total production of 137,494 kWh/yr. In Fig 4.3, DMap for Wind depicted. According to the DMap of Solar and Wind, wind energy production rose during the summer while solar energy production dropped.

Table 4.5 Summary of wind penetration and LCOE

Quantity	Value	Units
Peak Generation	92.7	kW
Wind Injection	227	%
Operating Time	5,593	hrs/yr
LCOE	0.145	$/kWh

Table 4.6 Annual average wind turbine output

Amount	Value	Units
Overall Installed Rating	100	kW
Average Generation	15.7	kW
CF	15.7	%
Overall Generation	137,494	kWh/yr

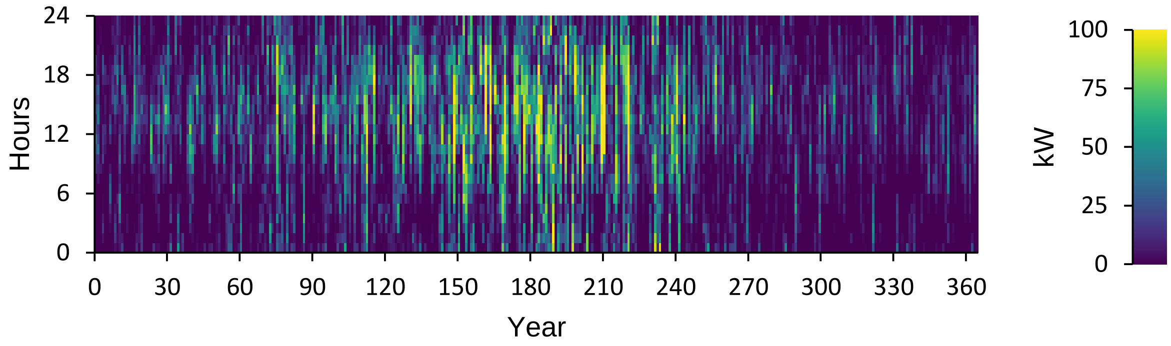


Fig. 4.3 DMap of Wind Turbine Output (KW)

4.1.4 Energy Storage Unit

A storage unit named Iron3500 was proposed during modelling, which lowered the project's LCOE than other battery banks. It used 968 kWh/yr and discharged 924 kWh/yr resulting in an erosion of 48.5 kWh/yr. As the microgrid was connected with grid so impact on BES reduced during unmet load. As a result, annual throughput was 948 kWh/yr and lifetime throughput was 572,040 kWh.

The electric load to storage bank capacity ratio determined the storage bank autonomy. Autonomy of it was 18.1 hr as per simulation data Table 4.9. Though it had a nominal capacity of 168 kWh/yr, usable nominal capacity was roughly 134 kWh/yr. State of charge of it was represented in the next Fig. 4.4. According to DMap its discharge frequency was elevated through April to July.

Table 4.7 Battery Storage Unit Installed Rating Data

Amount	Value	Units
BES	1.00	qty.
String Size	1.00	batteries
Strings in Parallel	1.00	strings
Output Voltage	48.0	V

Table 4.8 Battery Storage Unit Annual Operation Data

Amount	Value	Units
Energy Entered	968	kWh/yr
Energy Exhausted	924	kWh/yr
Storage Diminution	3.90	kWh/yr
Erosion	48.5	kWh/yr
Yearly Throughput	948	kWh/yr
Operating Time	665	hours

Table 4.9 Battery Storage Unit Annual Average Output and Throughput

Amount	Value	Units
Autonomy	18.1	hr
Storage Wear Cost	0.179	$/kWh
Rated Output	168	kWh
Real Rated Capability	134	kWh
Lifespan Throughput	572,040	kWh

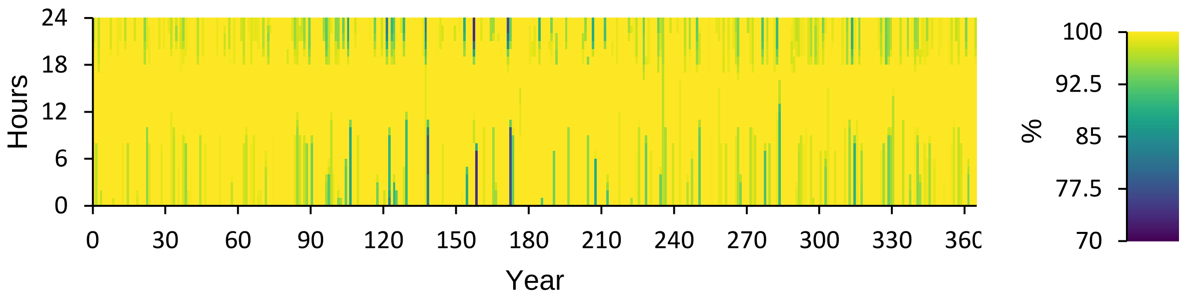


Fig. 4.4 DMap of the storage state of charge (%)

4.1.5 Converter

Simulation data of the converter given below in Table 4.10 and Table 4.11. Energy in and out of it were 43,630 kWh per year and 41.449 kWh per year, respectively, since it ran 4,685 hours per year. It had an overall capacity of 30kW, peak production of 28.3 kW, and a mean production of 4.73 kW. Here, rectifier efficiency and capacity factors were around 94.33% and 15.8% respectively. Inverter output frequency was much higher than converter output, as shown in the DMap below. As the system electric load was connected to the alternating current bus side, most of the time electricity flowed from the direct current bus to the alternating current bus.

Table 4.10 Electrical Overview of Converter

Amount	Value	Units
Working Time	4,685	hours/year
Energy Exhausted	41,449	kWh/year
Energy Entered	43,630	kWh/year
Losses	2,182	kWh/year

Table 4.11 Converter annual average output

Amount	Value	Units
Nominal Rating	30.0	kW
Average Production	4.73	kW
Lowest Production	0	kW
Peak Production	28.3	kW
CF	15.8	%

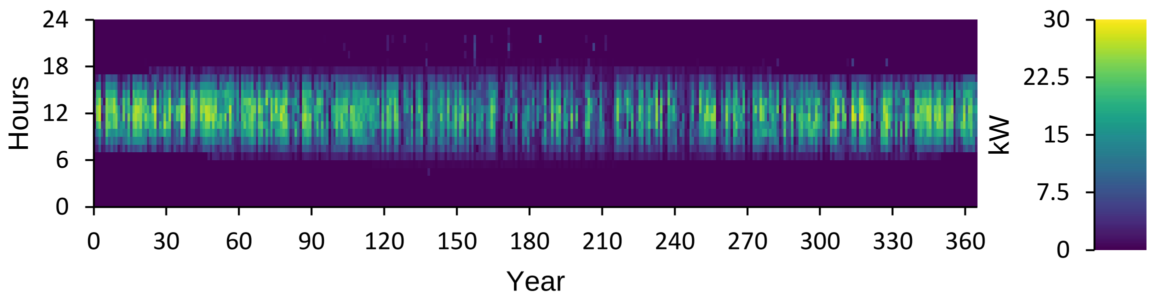
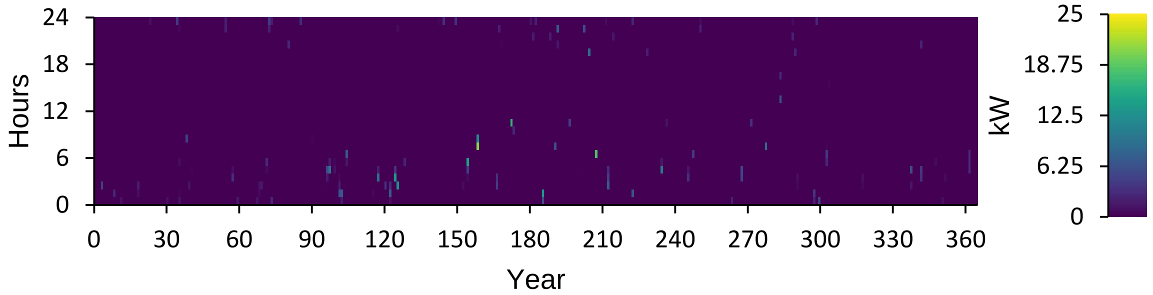


Fig. 4.5 DMap of the Inverter Production (KW)

Fig. 4.6 DMap of the Rectifier Production (KW)

4.1.6 Grid

The proposed microgrid was a grid connected system. From the economic perspective, its connectivity was very important. Grid energy sale lowered the



overall LCOE of the project because of revenue was generated from it. As per Table 4.12 data, Annual energy procurement and sale were approximately 14,440 and 127,876 kWh per year, correspondingly. The data provided within table below show that grid sales increased from March to August because microgrid had excess electricity at that time. The measuring and billing platform called NEM, reimburses proprietors of DG infrastructure for every kWh which can be sent to the power grid. Nearly -113,437 kWh/hr of electricity might be exported altogether using it.

Table 4.12 The transection profile of grid energy

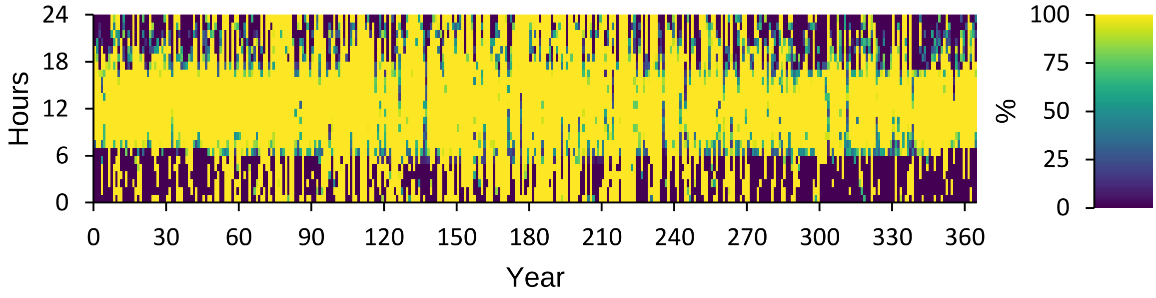
Month	Imported (kWh)	Exported (kWh)	Net Imported (kWh)	Limit (kW)	Cost
January	1,312	6,985	-5,673	10.0	-$397.12
February	1,125	7,173	-6,048	10.0	-$423.36
March	1,079	10,599	-9,519	10.0	-$666.36
April	946	12,373	-11,426	10.0	-$799.83
May	1,048	13,825	-12,777	10.0	-$894.37
June	829	19,025	-18,196	10.0	-$1,274
July	828	20,792	-19,964	10.0	-$1,397
August	1,148	15,659	-14,510	10.0	-$1,016
September	1,347	7,527	-6,181	10.0	-$432.64
October	1,655	4,303	-2,647	10.0	-$185.32
November	1,563	4,471	-2,908	10.0	-$203.59
December	1,559	5,145	-3,586	10.0	-$251.03
Annual	14,440	127,876	-113,437	10.0	-$7,941

4.1.7 Renewable Fraction Summary

The power sources used in this microgrid were entirely renewable, with the remainder purchased from the grid network, which was located adjacent to the project. As a result, total renewable production divided by load and generation are 93.7% and 92.6% respectively. The proposed microgrid generated 534% of total load, implying that the system had enough excess energy to sell. In Fig. 4.7 and Fig. 4.8, DMap of instantaneous renewable output percentage of total generation and load were depicted. It had been observed that renewable penetration was greatest during the 6 AM to 18 PM hour time period throughout the year.

Table 4.13 Renewable fraction summary

Energy-based metrics	Value	Unit
Aggregated RE generation divided by demand	93.7	%
Aggregated RE generation divided by generation	92.6	%
One minus aggregated non-RE generation divided by demand	100	%
Maximum amount	Value	Unit
RE production divided by demand	534	%
RE production by aggregated production	100	%
One minus non-RE production divided by aggregated demand	100	%



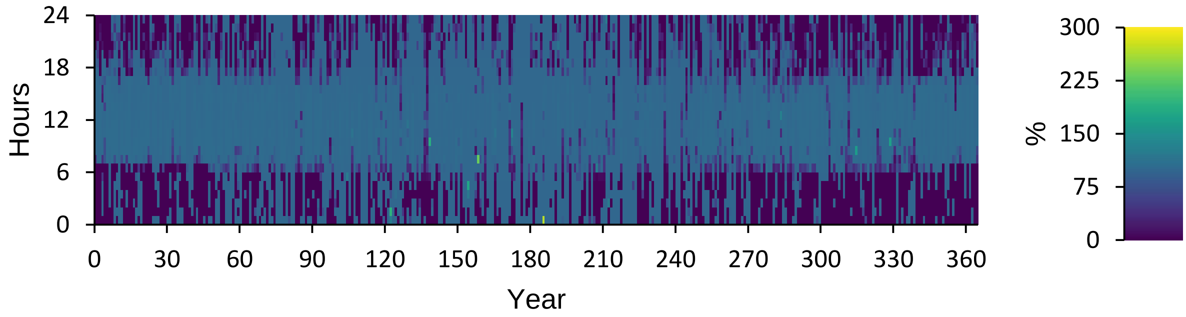


Fig. 4.7 DMap of Instantaneous RE Yield Ratio of Overall Production

Fig. 4.8 DMap of Instantaneous Renewable Output Percentage of Total Load

4.2 LF CONTROL ON THE PROPOSED MICROGRID

According to the LF approach, the battery began discharging when the system load demand exceeded the renewable generation. However, when the microgrid needs to acquire electricity through the power grid, as demonstrated in Fig. 4.9, battery charging is not possible. When the COE of the battery is greater than the COE of operating an alternator, the microgrid will not discharge the battery. If system buyed any electricity from the grid in a single timestep, the batteries couldnot be charged. As described in Section 3.2.1, this is obvious that only excess RE would be permitted for recharging BES under LF method. It would first meet the load with renewable energy. Before selling to

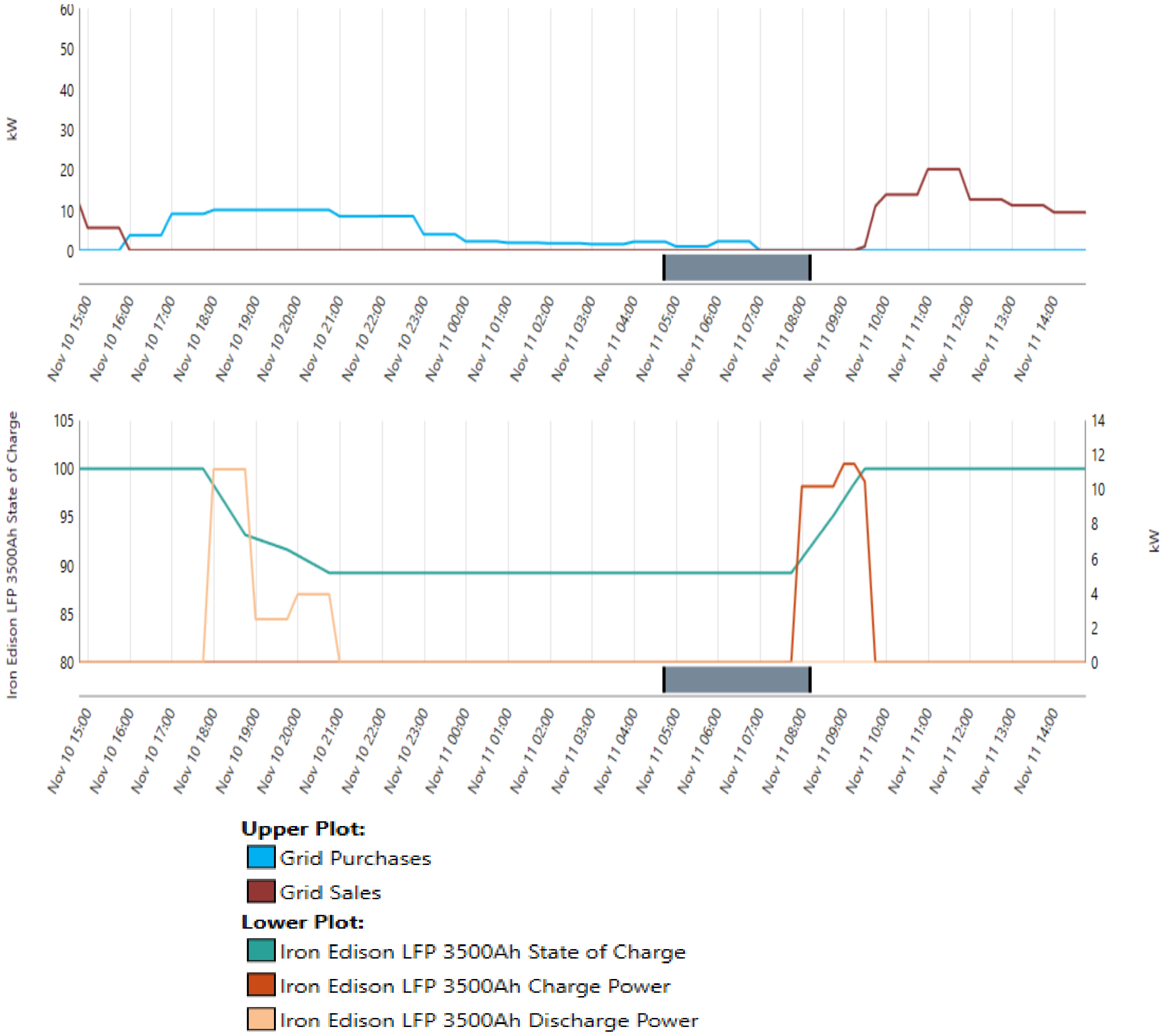


Fig. 4.9 Grid and Energy Storage response sample of a day.

the grid, system would charge the batteries as shown in Fig. 4.9. Any extra electricity would always be used to charge the batteries. If battery wear costs were too high, system may decide not to discharge the batteries to meet the connected system load.

4.3 DEFERABBLE LOAD IMPACT ON THE PROPOSED MICROGRID

Deferrable loads are considered to improve demand side optimization and control. Peak clipping intended to reduce maximum demand and maximum to mean proportion by approximately 31.2% and 7.5%, respectively [89].

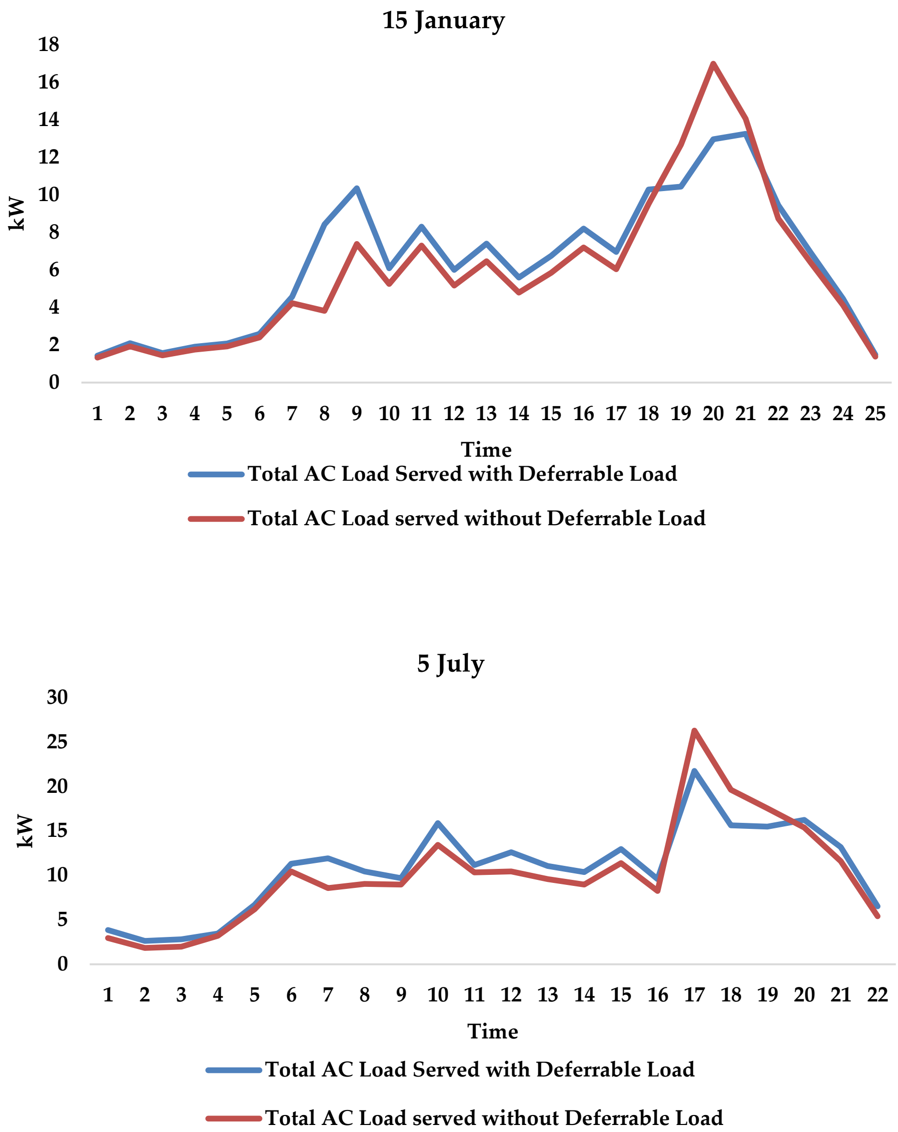
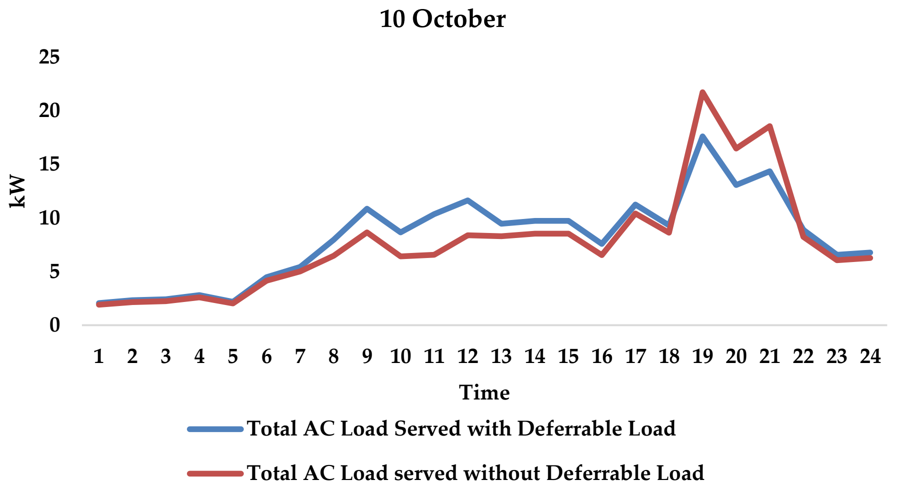


Fig. 4.10 Deferrable and without Deferrable Load Impact Chart of a day (15th January)

Fig. 4.11 Deferrable and without Deferrable Load Impact Chart of a day (5th July)

Fig. 4.12 Deferrable and without Deferrable Load Impact of a day (10th October)

Furthermore, load shifting provided greater flexibility to customers. Several samples were taken to demonstrate the impact of deferred load on grid optimization, as shown in Fig. 4.10 to Fig. 4.12. According to statistics from January 15th, when a microgrid had no deferrable demand, peak load was 14.06 kW, whereas peak load dropped to 12.96 kW when a microgrid had deferrable



load. According to data from the 10th of October, the peak load on the microgrid was 21.72 kW when there was no deferrable demand, and the peak load dropped to 17.61 kW when there was a deferrable load. It was so evident that deferrable load might shift some load during peak hours, ultimately preventing the start-up of numerous power plants or diesel generators.

4.4 FINANCIAL ANALYSIS OF THE PROPOSED MICROGRID

4.4.1 Cost Overview

According to element or expenditure classification, the cost overview exhibited cash flow depending on a current amount as well as an annualized expenditure. Tables 4.14 and Table 4.15, reported the annualized expenditure and NPC of every element. Wind turbines had the highest net present and annualized costs in the proposed microgrid, at $ 147,090 and $ 19,847 respectively. The NPC of the PV panel was $ 63,105, with an annual cost of $ 8,526. Energy storage units were more expensive than PV units, with net present and annualized capital cost of approximately $ 100,000 and $ 13,511 respectively. Implementation of the proposed microgrid could cost around $ 394,000 initially as capital expenditure.

Table 4.14 Net Present Costs

Name	Capital	Operating	Salvage	Total
Eocycle EO25 Class IIA	$200,000	$3,553	-$56,463	$147,090
Generic flat plate PV	$75,000	$2,220	-$14,116	$63,105
Grid	$0.00	-$58,770	$0.00	-$58,770
HOMER Load Following	$1,000	$148.03	$0.00	$1,148
Iron Edison LFP 3500Ah	$100,000	$1,499	-$55,527	$45,972
System Converter	$18,000	$2,220	-$3,388	$16,833
System	$394,000	-$49,130	-$129,494	$215,376

Table 4.15 Annualized Costs

Name	Capital	Operating	Salvage	Total
Eocycle EO25 Class IIA	$27,022	$480.00	-$7,629	$19,874
Generic flat plate PV	$10,133	$300.00	-$1,907	$8,526
Grid	$0.00	-$7,941	$0.00	-$7,941
HOMER Load Following	$135.11	$20.00	$0.00	$155.11
Iron Edison LFP 3500Ah	$13,511	$202.55	-$7,502	$6,211
System Converter	$2,432	$300.00	-$457.73	$2,274
System	$53,234	-$6,638	-$17,496	$29,100

4.4.2 Cash Flow

The currency movement chart gives an in-depth description of entire expenses incurred over the project's duration. The column represented every single year of the estimated project's lifespan. The rows listed the initial expenditure, cost of replacing it, estimated salvage amount, maintenance and operation expenditure, fuel expenses, and overall charge for every single part. According to Table 4.16, the initial investment of the project at year zero was around -$394,000. Initial expenditures are incurred solely at the beginning of the work. There were no capital costs after the initial year. From years 1 to 9, cash flow was approximately $6,638, primarily made up of component operating and maintenance expenses. The salvage price appears as an extra revenue for every element that was left operational at the end of the project's duration. The revenue at the conclusion found as salvage was $235,981.

4.4.3 Compare Economics

To figure out the financial viability of the planned microgrid, it must be compared with another microgrid known as the base case. While taking into account the overall expenses for each system, the contrast indicates the importance of the distinction involving two cases. Table 4.17 compares the cost and system architecture between the base and proposed system. The base case consists of PV capacity 50KW, 3 Wind turbine with the capacity of 25kW each, Grid peak purchase limit was 5 kW, 50 kW of Converter and a 3500AH Battery bank. On the other hand, proposed system consists of 30 kW PV, 4 Wind turbine, Grid limit 10kW, 30kW Converter and a 3500AH of Battery bank. Additionally, NPC and start-up expenses were less than in the base case.

Table 4.16 Cash flow table of the Proposed Microgrid

Year	0	1	2	3	5	6	8	9	10
Nominal									
EO25IIA									
Capital	-$200,000	$0	$0	$0	$0	$0	$0	$0	$0
Operating	$0	-$480	-$480	-$480	-$480	-$480	-$480	-$480	-$480
Salvage	$0	$0	$0	$0	$0	$0	$0	$0	$100,000
Fuel	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0
EO25IIA Total	**-$200,000**	**-$480**	**-$480**	**-$480**	**-$480**	**-$480**	**-$480**	**-$480**	**$99,520**
PV									
Capital	-$75,000	$0	$0	$0	$0	$0	$0	$0	$0
Operating	$0	-$300	-$300	-$300	-$300	-$300	-$300	-$300	-$300
Salvage	$0	$0	$0	$0	$0	$0	$0	$0	$25,000
Fuel	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0
PV Total	**-$75,000**	**-$300**	**-$300**	**-$300**	**-$300**	**-$300**	**-$300**	**-$300**	**$24,700**
Grid									
Capital	$0	$0	$0	$0	$0	$0	$0	$0	$0
Operating	$0	$7,941	$7,941	$7,941	$7,941	$7,941	$7,941	$7,941	$7,941
Salvage	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0
Grid Total	**$0**	**$7,941**	**$7,941**	**$7,941**	**$7,941**	**$7,941**	**$7,941**	**$7,941**	**$7,941**
LF									
Capital	-$1,000	$0	$0	$0	$0	$0	$0	$0	$0

Operating	$0	-$20	-$20	-$20	-$20	-$20	-$20	-$20	-$20
Salvage	$0	$0	$0	$0	$0	$0	$0	$0	$0
Fuel	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0
LF Total	**-$1,000**	**-$20**	**-$20**	**-$20**	**-$20**	**-$20**	**-$20**	**-$20**	**-$20**
Iron3500									
Capital	-$100,000	$0	$0	$0	$0	$0	$0	$0	$0
Operating	$0	-$202	-$203	-$203	-$202	-$203	-$203	-$202	-$203
Salvage	$0	$0	$0	$0	$0	$0	$0	$0	$98,343
Fuel	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0
Iron 3500 Total	**-$100,000**	**-$202**	**-$203**	**-$203**	**-$202**	**-$203**	**-$203**	**-$202**	**$98,141**
Converter									
Capital	-$18,000	$0	$0	$0	$0	$0	$0	$0	$0
Operating	$0	-$300	-$300	-$300	-$300	-$300	-$300	-$300	-$300
Salvage	$0	$0	$0	$0	$0	$0	$0	$0	$6,000
Fuel	$0	$0	$0	$0	$0	$0	$0	$0	$0
Replacement	$0	$0	$0	$0	$0	$0	$0	$0	$0
Converter Total	**-$18,000**	**-$300**	**-$300**	**-$300**	**-$300**	**-$300**	**-$300**	**-$300**	**$5,700**
Nominal Total	**-$394,000**	**$6,638**	**$6,638**	**$6,638**	**$6,638**	**$6,638**	**$6,638**	**$6,638**	**$235,981**

Table 4.17 Economic valuation of the Base and Proposed Case

Name	**Architecture**					**Cost**	
	PV (kW)	**EO25IIA (Nos.)**	**Iron3500 (String)**	**Grid (kW)**	**Converter (kW)**	**NPC ($)**	**Initial Cost ($)**
Base Case System	50	3	1	5	50	$239,704	$406,000
Proposed System	30	4	1	10	30	$215,376	$394,000

The present worth was what distinguished the NPC of both cases. A positive value implies that the proposed case preserves money throughout the life of the assignment, in contrast with the base case. The yearly value was calculated by analysing the present worth using the CRF. As per Table 4.18 data the proposed system present and annual worth were $ 24,328 and $ 3,287 respectively. It could be said that investing in the proposed system would save money and be economically worthwhile compared to the base case. According to the information in Table 4.19, the proposed microgrid's LCOE was $ 0.151 and its net current cost was $ 215,376, both of which were cheaper than the base case. Even still, the cost of operation and maintenance was nearly identical in both cases.

Table 4.18 Economic worth of the proposed case against the base case

Name	Proposed System
	Value
Present worth ($)	$24,328
Annual worth ($/yr)	$3,287

Table 4.19 Cost Comparison of the recommended case and base case

Name	Proposed System	Base System
	Value	Value
Net Present Cost	$215,376	$239,704
CAPEX	$394,000	$406,000
OPEX	-$24,134	-$22,468
LCOE	$0.151 /kWh	$0.178/ kWh
CO2 Released	9,126 kg/yr	6,776 kg/yr

4.5 FUTURE LOAD IMPACT ANALYSIS ON THE PROPOSED MICROGRID

4.5.1 System Response When Load Become Double

The greater the load demand, the more electrical power is required. Any viable microgrid should have the capability to withstand when load demand increases with respect to time. It was assumed that after 10 years electric load will be twice but system installed generation capacity will not be increased. To check the sustainability and feasibility of the proposed microgrid, the system load will be doubled from the present load. Hence, system response evaluated through simulation.

Present AC Primary Load = 165.59 kWh/d and 23.62 kW Peak

AC Primary Load after 10 years = 331.18 kWh/d and 47.24 kW Peak

4.5.1.1 Electrical Output Comparison

PV and wind output response was same as with the present and doubled load as per Table 4.21 simulation data. Though grid purchases increased from 14,440 kWh/yr (7.40%) to 29,715 kWh/yr (14.1%). As a result, the system's unmet load had nearly doubled, necessitating an increase in grid purchase. Due to the rise in load, the capacity shortage grew to 11,628 kWh/yr and the unfulfilled load to 758 kWh/yr, respectively.

Table 4.20 Excess and Unmet load when system AC primary load is double.

Amount	Value	Units
Excess Electricity	0	kWh/yr
Unmet Electric Load	758	kWh/yr
Capacity Shortage	11,623	kWh/yr

Table 4.21 Comparison between the generations of both case

	Present Electric Load		**Electric Load after 10 years**	
Element	Generation (kWh/year)	Proportion	Generation (kWh/year)	Proportion
PV	43,199	22.1	43,199	20.5
EO25IIA	137,494	70.5	137,494	65.3
Grid Purchases	14,440	7.40	29,715	14.1
Total	195,133	100	210,409	100

As system load considered twice as present load, so AC load consumption elevated from 60,442 kWh/yr (31.3%) to 120,126 kWh/yr (58%). Due to increased microgrid-connected load, grid sales fall to 39.8% from 66.3%, which also reduced project revenue.

Table 4.22 System consumption comparison between both cases

	Present Electric Load		**Electric Load after 10 years**	
Element	Usage (kWh/yr)	Proportion	Usage (kWh/yr)	Proportion
Main Load	60,442	31.3	120,126	58.0
Deferrable Load	4,564	2.37	4,563	2.20
Grid Sales	127,876	66.3	82,353	39.8
Total	192,882	100	207,042	100

4.5.1.2 Energy Storage Response Comparison

A comparison chart between the present load and the double load is shown in Tables 4.23. The value of energy entering and leaving the system raised by about 12.83 times when system ac primary load was double. Lifetime throughput and operating hour of the battery raised from 948 kWh/yr to 12,163 kWh/yr and 665 hr to 2,727 hr respectively.

Battery autonomy was the amount of time (in minutes or hours) that a UPS battery would last during a power outage at a particular load level. In simple terms, it referred to how long the UPS's inverter would operate solely on battery power. Due to the double load, autonomy value decreased to 9.39 hours while operational hours increased to 2,727 hours.

Table 4.23 Storage unit comparison between both cases

	Present Electric Load	**Electric Load after 10 years**	
Quantity	Value	Value	Units
Energy In	968	12,422	kWh/year
Energy Discharge	924	11,855	kWh/year
Storage Reduction	3.90	55.3	kWh/year
System Losses	48.5	622	kWh/year
Annual Throughput	948	12,163	kWh/year
Operating Hours	665	2,727	hours
Autonomy	18.1	9.39	hour

4.5.1.3 Converter Response Comparison

The output response of the converter under double load was much like the response under present load, as shown in the table below. Due to the impact of a double load, energy in value increased by 46,685 kWh/yr, or only about 13%.

Table 4.24 System converter output comparison between both cases

	Present Electric Load	**Electric Load after 10 years**	
Amount	Value	Value	Units
Operating Hours	4,405	5,169	hr/yr
Energy Discharge	41,084	46,685	kWh/year
Energy In	43,247	49,142	kWh/year
Losses	2,162	2,457	kWh/year

4.5.1.4 Grid Response Comparison

Assumed load would double in ten years, while system generation would stay the same. System unmet load surged as a result, forcing the microgrid to buy more power from the grid. Table 4.25 shows that annual energy purchases had nearly doubled while revenue from energy charges had decreased about 50%.

4.5.1.5 Economic Comparison

The system's LCOE increased from \$0.151 to \$0.168 as system revenue from grid sales decreased. The current system's capital expenditure was unchanged, but NPC had lower amount.

Table 4.25 Grid energy comparison between both cases

Present Electric Load					**Electric Load after 10 years**			
Month	**Imported (kWh)**	**Exported (kWh)**	**Net Imported (kWh)**	**Cost**	**Imported (kWh)**	**Exported (kWh)**	**Net Imported (kWh)**	**Cost**
January	1,312	6,985	-5,673	-\$397.12	2,586	4,131	-1,544	-\$108.10
February	1,125	7,173	-6,048	-\$423.36	2,146	4,416	-2,270	-\$158.91
March	1,079	10,599	-9,519	-\$666.36	2,246	7,007	-4,760	-\$333.23
April	946	12,373	-11,426	-\$799.83	1,971	8,308	-6,337	-\$443.60
May	1,048	13,825	-12,777	-\$894.37	2,223	9,372	-7,149	-\$500.45
June	829	19,025	-18,196	-\$1,274	1,832	14,243	-12,411	-\$868.76
July	828	20,792	-19,964	-\$1,397	1,930	15,697	-13,766	-\$963.65
August	1,148	15,659	-14,510	-\$1,016	2,336	10,695	-8,359	-\$585.14
September	1,347	7,527	-6,181	-\$432.64	2,927	3,581	-654	-\$45.77
October	1,655	4,303	-2,647	-\$185.32	3,421	1,077	2,344	\$138.32
November	1,563	4,471	-2,908	-\$203.59	3,084	1,504	1,580	\$93.20
December	1,559	5,145	-3,586	-\$251.03	3,013	2,323	690	\$40.71
Annual	14,440	127,876	-113,437	-\$7,941	29,715	82,353	-52,638	-\$3,735

Table 4.26 Economic Comparison between both cases

	Current System	**Current system with double load**

Net Present Cost	$215,376	$257,570
CAPEX	$394,000	$394,000
OPEX	-$24,134	-$18,433
LCOE	$0.151 /kWh	$0.168 /kWh
CO2 Discharged	9,126 kg/year	18,780 kg/year

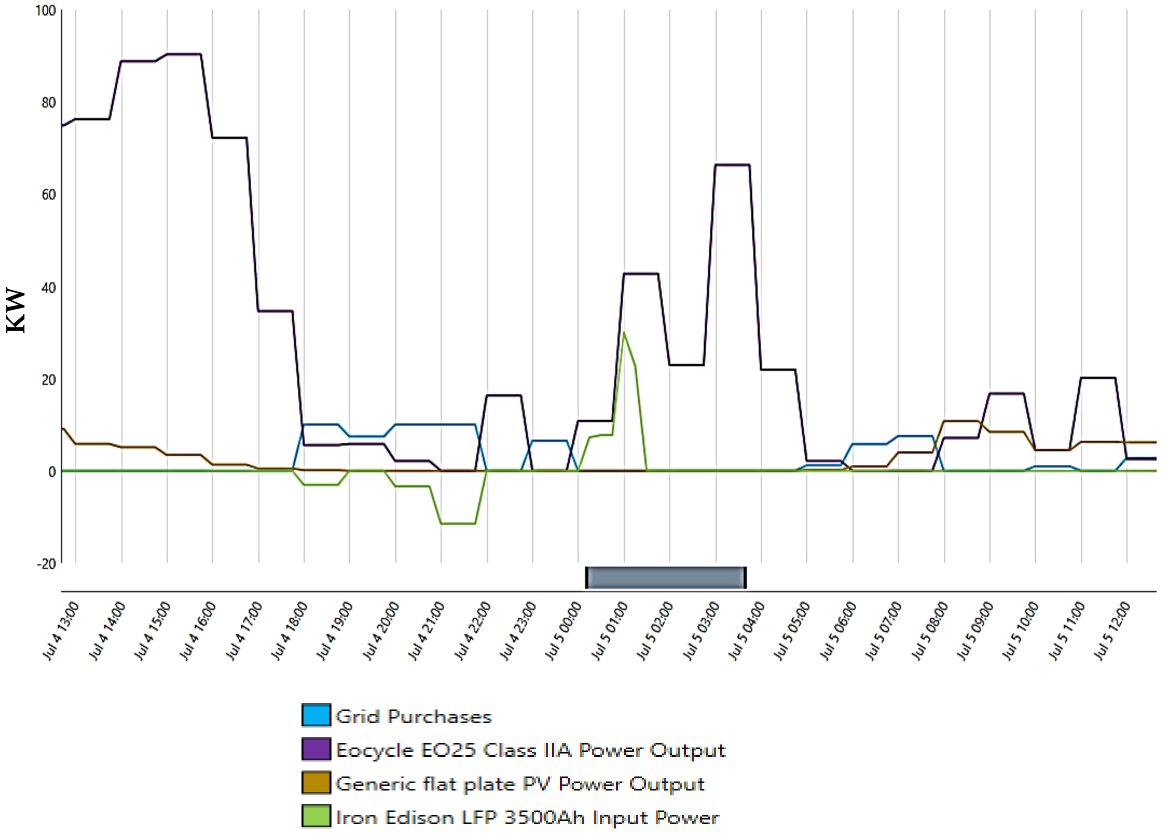


Fig. 4.14 Power Source response of the proposed microgrid.

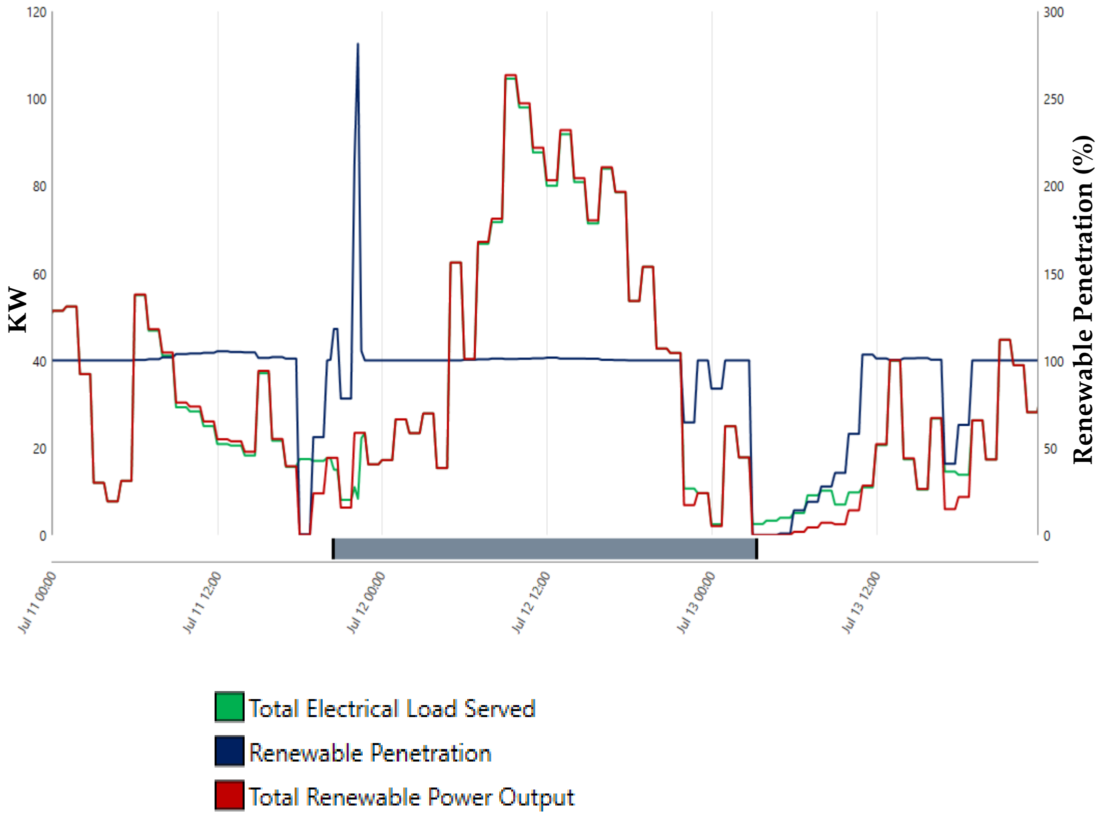


Fig. 4.13 Renewable generation of the proposed microgrid.

4.6 TIME SERIES PLOTS OF THE PROPOSED MICROGRID

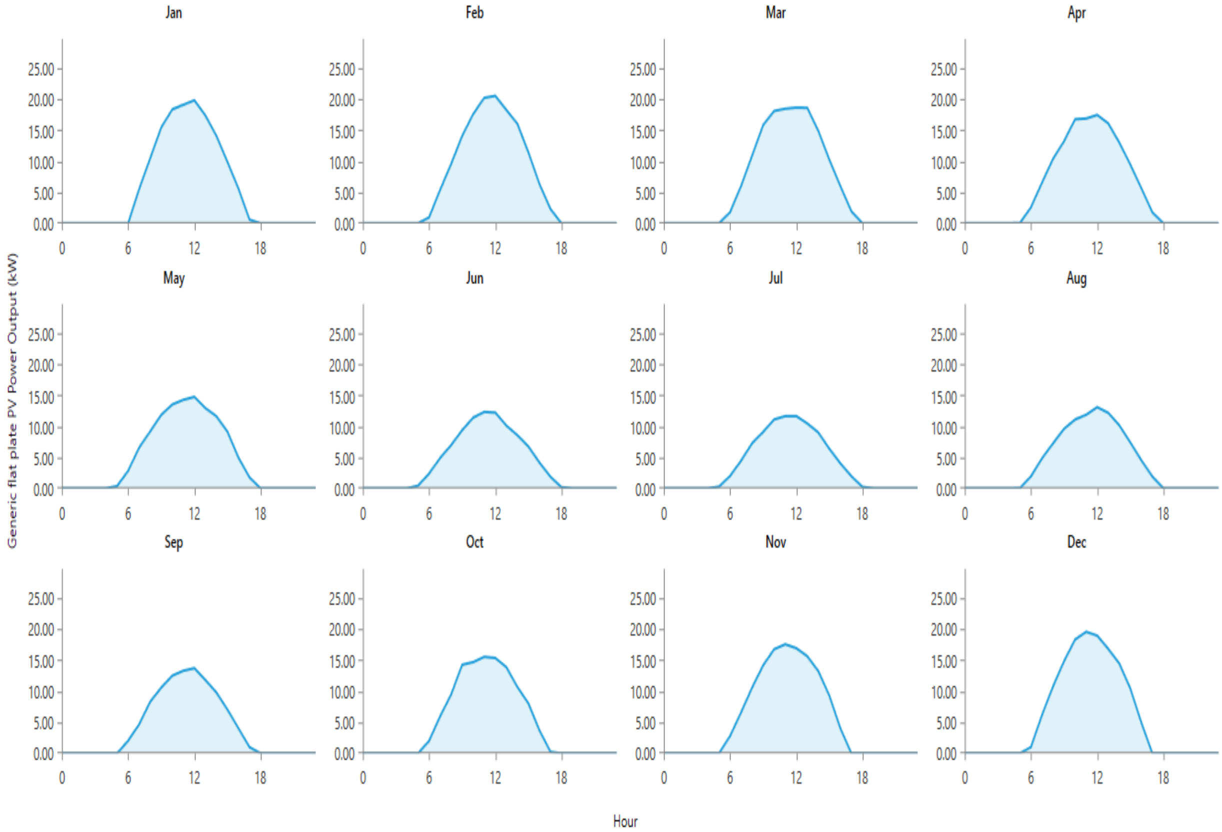


Fig. 4.15 Daily profile of PV power output.

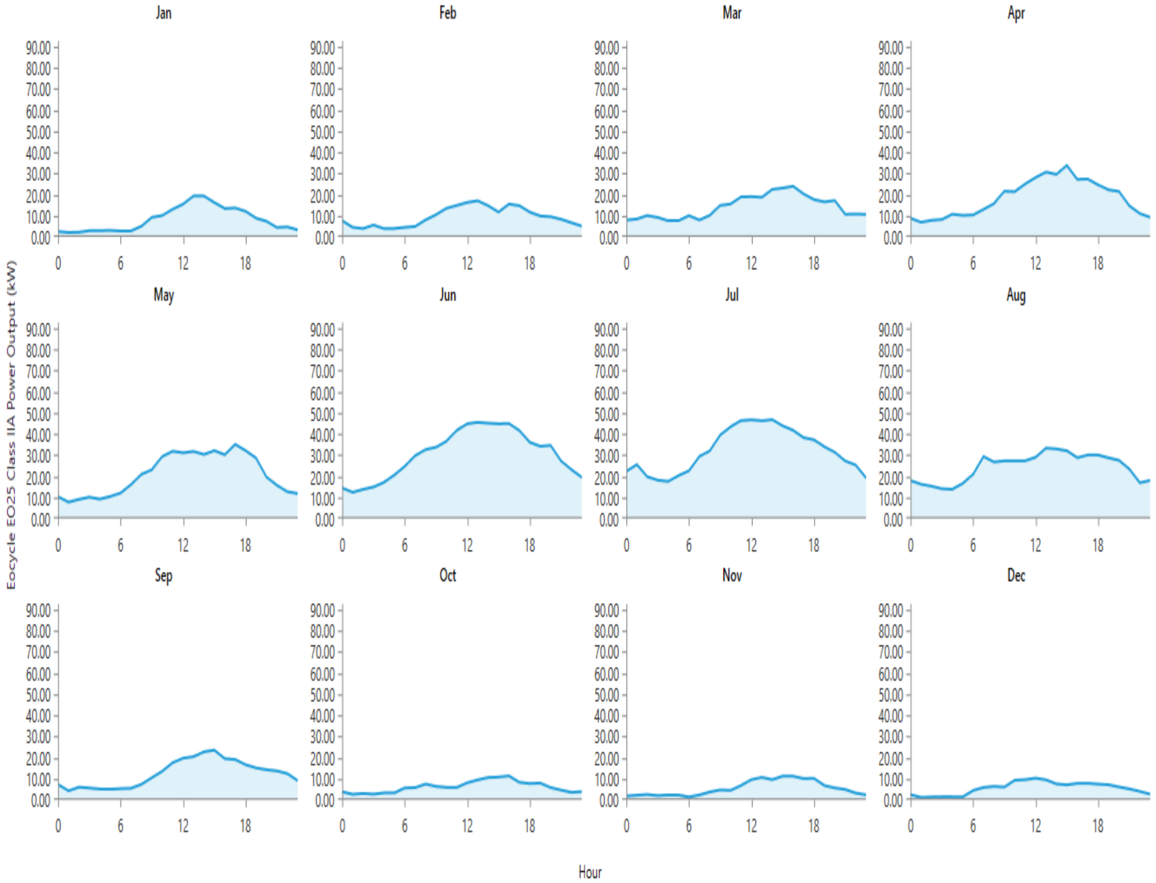


Fig. 4.16 Daily profile of Eocycle EO25 power output.

In this chapter, the homer pro simulation output data of the proposed microgrid has been included and analysed. Renewable generation, grid transaction, system consumption and all other significant system output data are stated in this section. I have verified the LF technique's capability in section 4.2. Using this dispatch technique system smoothly handles renewables and energy storage. Grid transaction following net energy metering policy to purchase or sell grid energy in section 4.1.6. The deferrable load has proven the techno-economic impact of it through peak load clipping. Lastly in section 4.5, the proposed microgrid can handle double than current electric load, which proves that the system is technically and economically feasible.

5 Conclusions

All of the research is summarized in this part, from its introduction through the results. Section 5.2 of this research presents its main outcomes. The dissertation's limitations are discussed in Section 5.3. It talks about how to make the study stronger and better. Section 5.4 expresses the implication of the thesis work. It discusses some findings that can be drawn from the practical value and the indirect conclusion of the thesis work. The final section, 5.5, discusses potential future developments for this investigation.

5.1 GENERAL

The demand for power around the world is rising every year as a result of population growth and the degree of industrialization. Engineers in the power sector must devise a solution to meet this demand. Without the discovery of significant new fossil fuel sources, it could be assumed that the end of fossil fuel-based technology by the end of this century. Consequently, clean energy is gaining popularity. The RE technologies with the quickest growth are PV and

WT. By 2041, our government hopes to have 20% of its energy needs met by renewable sources. And the majority of it will be generated by Solar PV and Wind energy. We had concentrated on an on-grid solar-wind hybrid microgrid at coastal area for this reason.

A drop in the LCOE and a boost in the utilization of RE are two benefits of implementing an integrated network consists of PV, WT, and BES. The leading generator dispatch control method LF is applied as the energy governance algorithm in this integrated microgrid system. LF is used as the EMS methodology in this hybrid microgrid system. Though, this algorithm had drawbacks, and its performance was dependent on system characteristics such as load pattern and regional solar radiation levels etc. [27]. Conclusions are summarized below:

- I have designed a grid connected microgrid system.
- I have investigated the LF dispatch technique's capability to handle RE, grid energy, and battery storage.
- Using LF and the deferrable load concept, the overall LCOE was reduced.
- The cost calculation of the microgrid lifespan period was investigated.
- I have reviewed several previous works and compared them with our proposed system.
- An economic comparison between the proposed system and a base case had been shown and verified

5.2 KEY FINDINGS

I had simulated the proposed microgrid for a tentative project period of 10 years. Key findings of the proposed microgrid are given below:

- Recommended microgrid was more affordable than any other case studied during analysis.
- As per LF algorithm, it restricted the energy storage device to charge when there was an unmet load.
- And when the microgrid had any excess RE, it was used to charge batteries then export to the grid.
- Besides, deferrable load decreased the system impact of the load during peak hour.
- Even if load become double, proposed microgrid is economically feasible.

5.3 LIMITATION OF THE STUDY

More decisive results could have been obtained if real-time simulation had been possible. Here, every outcome was based on an offline simulation. If we were able to utilize actual air density data, the recommended microgrid solution would have been more realistic and dependable. Should think about maintenance and operation obstacles, skilled technical personnel, and skilful manpower issues. Its maintenance shutdown interval was ignored in this thesis. To implement and attract the local consumer about deferrable load concept is not an easy task. Current Dollar crisis might raise the projected microgrid's overall LCOE.

The BES's SoC may be fully drained at times, when RE output is reduced. This could shorten the BES lifetime if it continues over an extended period of time and is repeated. Furthermore, the grid interface was allowed for supplying the remaining demand while BES was allowed to release energy and unable to fulfil the demand. This operational scenario may cause the grid to run an alternator at a reduced capacity, lowering its operational usefulness.

5.4 IMPLICATION

Though this study focused on LF strategies for Renewables and Energy storage of a 1.3 MWp power plant, the proposed Microgrid with LF technique can be applied to renewable power plants of even larger sizes. This also implies that with a larger capital investment, solar-wind projects with energy storage become feasible. According to [90], the cost of BESS decreases as storage capacity increases. As a result, we can conclude that incorporating BESS into very large-scale solar-wind power plants will result in less economic stress than it does for smaller scale power plants like the ones studied here.

5.5 RECOMMENDATION FOR FURTHER STUDY

This research could be taken to a new level in future, as discussed below:

- For optimizing the microgrid design, the studies could be strengthened by taking into account the actual measured data of the wind speed and sun irradiation over a year. In this work, these data have been taken from NASA as mentioned previously.
- Instead of using LF strategies another dispatch strategy named Cycle Charging method could be used and analysed.
- Furthermore, the cost of battery degradation, which was not considered, could be investigated in the future as it affects the changing or replacement of batteries or storage devices.
- This thesis lacks information about Net Energy Metering (NEM) and Smart Grid Network, but in the future, it might be elaborated and investigated from Bangladesh's point of view.

When the RE output is insufficient to meet demand, LF will deploy a generator or grid interface to inject electricity into the connected system.

In this chapter, I have summarized how successfully the work has been concluded. In section 5.2, achieved key goals of the thesis are summarized and the recommended microgrid was more affordable than any other case studied during analysis. There are some limitations of the thesis which are discussed in section 5.3. In the last section of this chapter, I have recommended several topics for future study. Finally, this thesis will help governments and researchers build a smart grid and promote renewable generation in Bangladesh.

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Appendices

Appendix A: Engineering details of the several components of the Proposed Microgrid.

PV:

It has 30.0 kW of rated output. The generated output is 43,199 kWh per year.

Nominal Rating	30.0 kW
Initial Expenditure	$75,000
Definite Production	1,440 kWh/kW
PV Diffusion	71.5 %

Overall Generation	43,199 kW
Servicing Expenditure	300 $/yr
LCOE	0.197 $/kWh

Wind Turbine: EO25 IIA

The 100 kW WT produces 137,494 kWh per year.

Number	4
WT Overall Generation	137,494 kWh/yr
Initial Expenditure	$200,000
Wind Turbine Lifetime	20.0 years

Rated Capacity	100 kW
Hours of Operation	5,593 hrs/yr
Maintenance Cost	480 $/yr

Storage: Iron Edison LFP 3500Ah

The estimated ability of the BES is 168 kWh with the throughput of 948 kWh per year.

Nominal Rating	168 kWh
Usable Capacity	134 kWh
Annual Throughput	948 kWh/year
Servicing Expenditure	200 $/year
Autonomy	18.1 hour

Initial Expenditure	$100,000
Losses	48.5 kWh/year

Data Sheet of EO25IIA:

eocycle
PERFORMANCE & RELIABILITY, HASSLE FREE

TECHNICAL SPECIFICATIONS
E025 Class III wind turbine

CHARACTERISTIC		SPECIFICATION
Main Data	Model	EO25
	Design class	IEC Class IIIA wind turbine
	Design life	30 years minimum without major component replacement
	Rated power	25 kW
	Rated wind speed	Average annual wind speed: 7.5 m/s (27 km/h)
	Cut-in | Cut-out wind speed	2.75 m/s (9.9 km/h) | 20 m/s (72 km/h)
	Extreme wind speed	52.5 m/s (189 km/h), 3-second average
	Operating temperature	-20 °C to 40 °C (-4 °F to 104 °F)
	Lightning protection	Lightning rod, surge protection devices, grounding system
	Certifications	IEC 61400-2, MCS, AWEA 9.1, UL1741, CE, CSA 22.2, G59/3
Rotor	Rotor diameter	15.8 m (51.8 ft)
	Swept area	196.3 m² (2112.9 ft²)
	Rotor speed	Variable, up to 53 rpm
Generator	Type	Transverse flux synchronous permanent magnet generator Eocycle-C5000
	Model	3-phase
	Generator	25 kW, 415 V, 42.4 Hz, 1.25 service factor
	Drivetrain	Direct drive (no gearbox)
	Generator enclosure and insulation	Totally enclosed, weather-proof, class F insulation, IP56, maintenace free
Power Converter	Type	Grid-tied / utility-interactive
	Converter model	ABB ACS800-11
	Converter output	3-phase, 380 V to 500 V, 50/60 Hz, 60A, Power Factor 0.99
Control System	Controller model	MitaTeknik WP130 MK II
	Advanced features	Data logging and direct integration with safety system
	SCADA/Monitoring system	MiScout, web and mobile application
	Control strategy	Maintenance free active stall-regulated
	Weather sensors	Wind speed, wind direction, temperature
Yaw System	Type	Active hydraulic slew drive
Materials	Steel components	High quality, as per ASTM standards
	Corrosion protection	Hot-dip galvanized or zinc-coated, as per ASTM standards
Braking System	Normal operation	Combination: 1) generator 2) stall blade design 3) yaw-assist
	Emergency rotor brake	Fail-safe hydraulic disk brake
Blade	Model	Eocycle
	Design	Fixed-pitch (no moving parts)
	Length	7.6 m (24.9 ft)
Tower	Hydraulic tower - hub height	16.8 m (55.1 ft) or 23.8 m (78.1 ft)
	Finish	Galvanized, white paint

Version: 2019-02-07

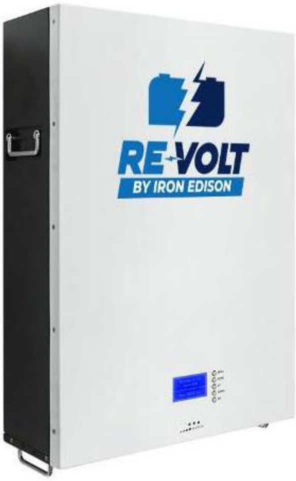
Data Sheet of EO25IIA:

IRON EDISON RE-VOLT

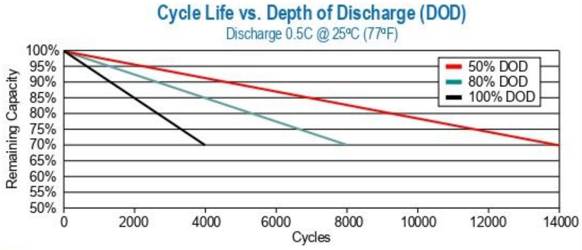
Lithium Iron Phosphate (LiFePO4) Battery

TECHNICAL SPECIFICATIONS

Revised 08/2022



Renewable Energy, Off-Grid & Backup Power Applications
Safest Lithium-Ion Chemistry - LiFePO4
Maximum Compatibility with Industry Standard 48v Equipment
Integrated Battery Management System
Stackable for Additional / Scalable Energy Storage
10 Year Warranty and Lifetime Technical Support



ELECTRICAL SPECIFICATIONS

	REVO-5000	REVO-10000
Nominal Voltage	51.2 Vdc	
Operating Voltage	48 - 56 Vdc	
Ah Capacity	100	200
Total Energy	5120 Wh	10240 Wh
Recommended Charge Current	20 - 25 A	40 - 50 A
Max Charge Current	100 A	100 A
Max Discharge Current	100 A	150 A
Max Batteries in Series	1	
Max Batteries in Parallel	15/16, Call for larger systems	

CHARGE SPECIFICATIONS

	REVO-5000	REVO-10000
Bulk / Absorb Voltage	55.6 V	
Absorb Time	6 - 15 Minutes	
Absorb End Amps	5 A	10 A
Float Voltage	53.4 V	
Recharge / Rebulk Voltage	52.6 V	
Generator Start Voltage	51 V	
Low Battery Cutout	48 - 49 V	

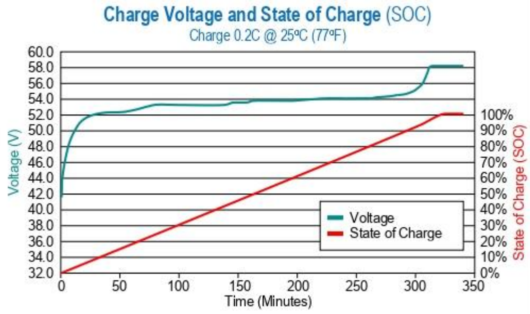
PHYSICAL SPECIFICATIONS

	REVO-5000	REVO-10000
Dimensions (L x W x H)	28.25 x 19.06 x 8.25 in. (71.75 x 48.42 x 20.95 cm)	
Weight	130 Lbs (58.5 kg)	215 Lbs (97.5 kg)
Shipping Classification	UN 3480, Class 9	
Certifications	UL1642, UL1973 (cells), IEC 62619, CE, UN38.3, RoHS	
Enclosure Rating	IP 21	

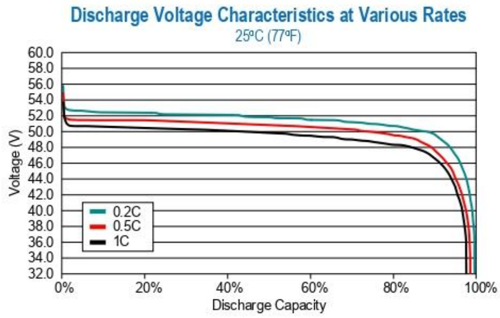
TEMPERATURE SPECIFICATIONS

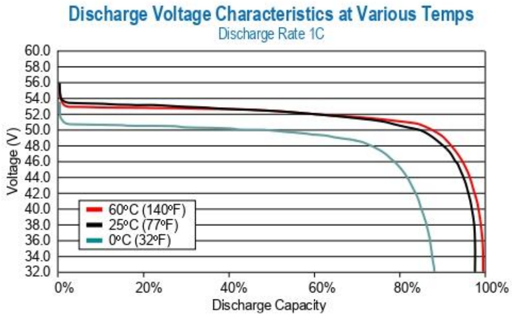
Operating Temperature	0ºC to 45ºC @ 60% +/- 25% Relative Humidity
Storage Temperature	-20ºC to 60ºC @ 60% +/- 25% Relative Humidity

Stated capacities are at the 20-hr discharge rate



- Charging at Recommended Charge Current to Bulk Termination / Absorb Voltage (1-Stage Bulk, aka CC) will charge the battery to approx. 95% SoC
- Charging at Bulk Termination / Absorb Voltage to Absorb Termination Current (2-Stage Bulk+Absorb, aka CC/CV) will charge the battery to 100%SoC
- Equalization Charging is not needed or recommended
- Temperature compensation of charge voltage is not required





720-432-6433

IronEdison.com

UN38.3

Converter:

Rating	30.0 kW
Average Production	4.73 kW
Lowest Production	0 kW
Peak Production	28.3 kW
CF	15.8 %

Availability of Application	4,685 hrs/yr
Energy Discharged	41,449 kWh/yr
Energy Entered	43,630 kWh/yr
Wastage	2,182 kWh/yr

Appendix B: Report on input data for the proposed microgrid

Input Summary

Project title	Grid Connected Microgrid having Renewables and Energy Storage
Author	Moon Barua
Notes	30kW PV, 100kW Wind, 3500AH Battery, 30kW Converter

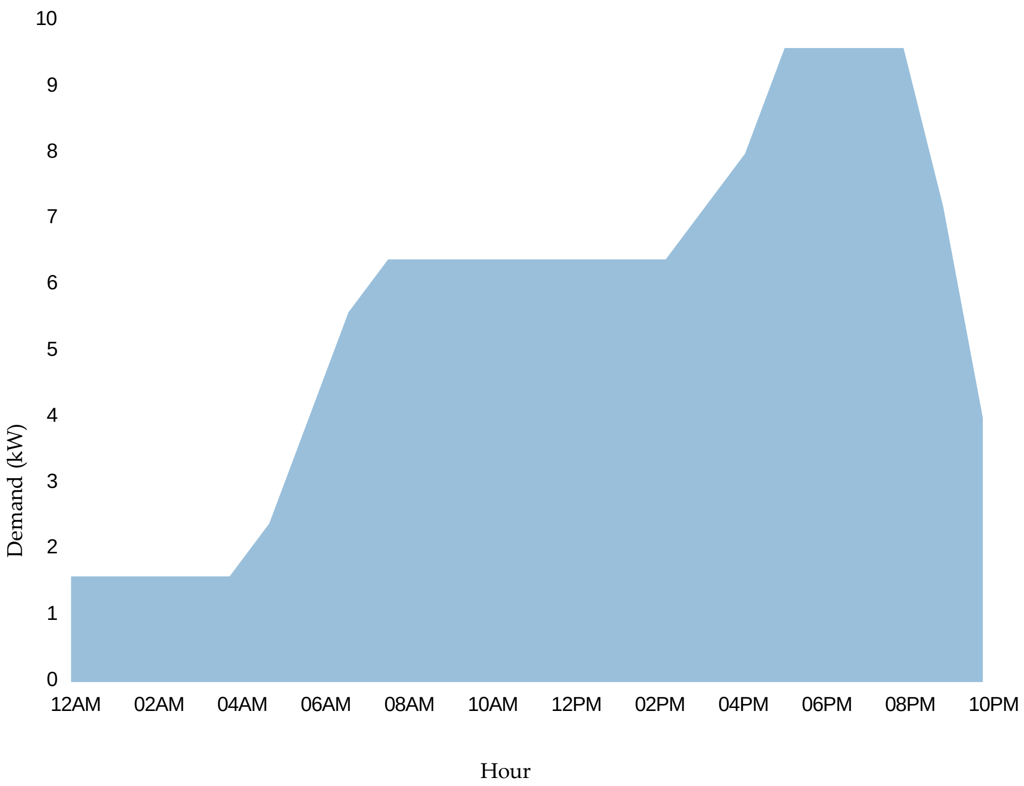
Project Location

Location	GMPX+39 Sultana Mondir, Sitakunda, Chattogram, Bangladesh.
Latitude	22° 32"11' Northward
Longitude	91 °41"91' Eastern
Time region	Dhaka, BD

Electric Load

Information basis	Synthetic
Regular tumult	10%
Hourly tumult	20%

Yearly mean	165.594 kWh/d
Maximum Demand	23.6183 kW
Demand Factor	0.2921



Regulator: LF

Number	**Investment**	**Spare**	**O&M**
1	$1,000.00	$200.00	$20.00

The reduction technique	Financial
Permit several alternators to run at once	Yes
Permit processes with an alternator rating that is below the optimum load.	Yes
Enable gasoline engines to be turned off.	Yes

PV:

Estimated size	30
Period	15 yr
Factor of reduction	80%
Monitoring technology	No Tracking
Angle	22.535 deg
Horizon	0.000 deg
The reflection of the surface	20.0%

Wind Speed (m/s)

WT:

Amount	Initial Investment	Replacement	O&M
1	$50,000.00	$50,000.00	$120.00

Battery: **Iron Edison LFP 3500Ah**

Amount	Investment	Spare	O&M
1	$100,000.00	$100,000.00	$200.00

Converter

Size	Investment	Spare	O&M
1.00	$600.00	$600.00	$10.00

Estimated sizes	30,50 kW
Period	15 yr
Inverter and Alternator are capable of operating in tandem	Yes

Finances

Nominal interest charges per year	6%
Scheme period	10 year
Penalty for Power Deficit	$0/kWh

Process Regulator

Time frame	15min
Multiple year permit	No
Enable multiple-alternator setups	No
Permit setup with several type WT	No
BES autonomy edge	2
Peak RE injection edge	55
Alarm about RE Injection	No

Optimizer

Peak calculations	10000

Scheme strategy exactness	0.01
NPC exactness	0.01
Attention factor	50
Optimize group champions	Yes

Restrictions

Peak yearly capacity deficiency	10
Lowest RE percentage	80
Functional standby fraction of hourly demand	10
Functional standby fraction of highest demand	40
Functional standby fraction of PV generation	40
Functional standby fraction of WT generation	50