PROJECT REPORT
ON

"Economic Management of Alternate Energy Sources for Electric Power Generation"

SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENT FOR THE DEGREE OF

BACHELOR OF ELECTRICAL ENGINEERING

SAVITRIBAI PHULE PUNE UNIVERSITY

BY

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UNDER THE GUIDANCE OF

PROF. DR Mrs. V. S. JAPE

DEPARTMENT OF ELECTRICAL ENGINEERING

PES's MODERN COLLEGE OF ENGINEERING,

PUNE -05

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PES's MODERN COLLEGE OF ENGINEERING
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CERTIFICATE

This is to certify that the project entitled Title of the project: Economic Management of Alternate Energy Sources for Electric Power Generation

Has been carried out successfully by

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It is bonafide work carried out by them under supervision of Prof. Dr. Mrs. V.S. Jape and is approved for the partial fulfilment of requirement of Savitribai Phule Pune University, for the award of the Degree of Bachelor of Electrical Engineering.

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ABSTRACT:

This Project deals with the economic analysis of a hybrid energy system comprising solar PV(1kw, 2channel), wind turbine(1.5kw), Batteries(12v, 200Ahr, 10 no.) and Hydrogen Fuel Cell(500W, PEM Type). The simulation is performed in HOMER(hybrid optimization of multiple energy resources) software. The simulation studies give information about the different economic and technical parameters of a given hybrid system which is used to access its technical and economical feasibility. For this hybrid system, the metrological data of Solar Radiation, and hourly wind speed for the given location are taken from NASA. The given system is grid connected system. The load for the system is 46.01kWh/day, with a peak load of 9.58kw. The objective of this study is to evaluate the optimal system configuration that would minimize the cost of energy.

HOMER (Hybrid Optimization Model for Electric Renewables) software is a powerful tool used for the analysis, optimization, and economic evaluation of hybrid renewable energy systems. This software enables the integration of multiple energy sources such as solar, wind, hydro, biomass, and conventional generators to meet the electricity demands of various applications.

Case study of 6 different combination of energy resources is made. 1) only Grid, 2) Grid + PV(1 kW), 3)Grid + Solar PV(1 kW) + Wind turbine(1.5 kW), 4) Grid + PV + wind tubine + Hydrogen Fuel Cell, 5) Grid + Solar PV + Wind Turbine + Hydrogen fuel cell + Batteries, 6) Homer optimized combination.

Acknowledgement:

As we are in our final semester of BE Electrical Engineering, we are aware that without the guidance of our beloved professors, it would not have been possible to complete and present this project. It gives us immense pleasure in having an opportunity to express a deep sense of gratitude to our Principal, **Dr. Mrs. K.R. Joshi**, for providing us with the necessary facilities. We are also very thankful to our Head of Department, **Dr. Mrs. N.R. Kulkarni** for her time-to-time guidance and support.

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We are also thankful to all the professors and staff members of the electrical department for the advice, suggestion, and criticism.

Summary:

CHAPTER 1) INTRODUCTION:

This chapter deals with the overview of the need for renewable energy sources for reliable and efficient electric power generation. The introduction and use and importance of HOMER software are covered in this chapter. A detailed idea about of project's aim and objective is covered.

CHAPTER 2) LITERATURE REVIEW:

This chapter deals with the historical background of different work related to the project topic. The literature review detailed the work published by many writers in both national and international publications. The review briefly describes each paper's contents and how beneficial they are to the current project. This study significantly influences the choice of subject and sheds information on the field's future needs.

CHAPTER3) SYSTEM CONFIGURATION:

This chapter deals with the system block diagram and schematic diagram of the system.

CHAPTER 4) METHODOLOGY:

In this chapter methodology of the project is explained. This includes a collection of different data. The data includes the solar radiation, average wind speed at a given location, and the daily and annual electrical load profile

CHAPTER 5) SIMULATION AND RESULTS:

Results regarding system performance in terms of economic and technical aspects are included in this chapter. There is a comparison between the system's performance parameters with and without HOMER optimization. NPC, COE, and initial capital cost are some examples of the economic performance criteria. The system's yearly energy generation is one of the technical specifications.

CHAPTER 6) CONCLUSION AND DISCUSSION:

The conclusion of the project is mentioned in this chapter. This conclusion is reached by comparing all the outcomes of optimized cases versus unoptimized cases.

CHAPTER 7) FUTURE SCOPE:

The future scope of the project topic is discussed in this chapter. The future scope includes the

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION:

The use of renewable energy sources for electric power generation is increasing as the world is concerned about global warming due to conventional electric power generation plants. India is one of the world's fastest-developing nations. In India, too, the energy demand is mostly met by non-renewable sources, which contributes to its carbon emissions, making the Indian government more inclined to produce clean energy. The development of the renewable energy sector in India has been important. The only one source of Renewable energy is not capable of continuously supplying power to the load, so hybrid energy systems become an important option to maintain feasibility between power and load.

The efforts in using renewable energies have often focused on single technologies. But single renewable energy source often unable to cater to consumers' needs adequately and reliably due to the intermittent nature of renewable energy sources. Reliance on a single source generally results in an oversizing of the system, thereby increasing the initial costs. Hybrid systems comprising different renewable energy sources can overcome the intermittent nature of renewable energy sources, and the oversizing issue and enhance the reliability of supply. Yet, hybrid systems have received less attention due to their high complexity. Different authors around the world have carried out several studies on power generation using different hybrid system. However, only a few studies are reported in India on power generation using a hybrid system.

The purpose of this simulation analysis is to find the best combination of Renewable energy technologies from the available resources in a given location that can meet the electricity demand in a reliable and sustainable manner and to analyse whether such a hybrid option is a cost-effective solution or not. To achieve this objective, Daily load curve is calculated, Metrological data of Solar Radiation and hourly wind speed data for a given location.simulation for the given system parameters in HOMER are performed. Here we have analysed Grid connected hybrid system comprising Solar PV(1 Kw), Wind turbine (1.5kw), and Batteries (12V, 200A, 10nos).

1.2 Project Motivation:

1. Environmental Concerns: The project may be motivated by the need to address environmental challenges and reduce reliance on conventional fossil fuel-based power generation. By exploring alternate energy sources such as solar, wind, hydro, or biomass, the project aims to contribute to a more sustainable and environmentally friendly energy mix.

2. Cost Reduction: Another motivation could be the desire to explore economically viable alternatives to conventional energy sources. Rising fuel costs and the potential for price volatility in the future may make renewable energy sources more attractive from an economic perspective. The project can analyze the feasibility and cost-effectiveness of different renewable energy technologies to optimize the economic benefits.

3. Energy Security: Diversification of energy sources can enhance energy security by reducing dependence on imported fuels. The project may aim to assess the feasibility of integrating renewable energy systems into the existing power infrastructure to enhance the resilience and reliability of the electricity grid.

4. Policy Compliance: Governments and regulatory bodies often set renewable energy targets and incentives to promote sustainable energy generation. The project may be motivated by the need to comply with such policies and regulations, ensuring that the energy generation mix aligns with the broader energy transition objectives.

5. Technological Advancements: The project could be driven by the desire to explore and evaluate the performance of emerging renewable energy technologies. HOMER software can assist in analyzing and optimizing the operation of hybrid renewable energy systems, considering factors such as resource availability, system sizing, and storage requirements.

6. Community Engagement: The project may be motivated by community engagement and public participation. By analyzing and presenting the economic and environmental benefits of alternative energy sources, the project can raise awareness and encourage public support for the adoption of renewable energy systems.

Overall, the motivation for the project lies in the pursuit of a sustainable, cost-effective, and reliable energy generation system that aligns with environmental goals, economic considerations, and policy objectives.

1.3 Project Aim and Objective:

Project Aim:

The aim of this project is to explore the economic management of alternate energy sources for electric power generation using the HOMER software. The project aims to analyze the feasibility and economic viability of integrating different renewable energy sources into the power generation system.

Objectives:

1. To evaluate the potential of different alternative energy sources: The project will assess the suitability and availability of various renewable energy sources such as solar, wind, hydro, biomass, etc., in the target region. It will analyze their potential for electric power generation and identify the most promising options.

2. To study the HOMER software: The project will familiarize itself with the HOMER software, which is a widely used optimization tool for analyzing and designing hybrid power systems. The objective is to understand the capabilities and features of the software in order to make effective use of it for economic management analysis.

3. Modelling of the hybrid power system: Using the HOMER software, the project will develop a model that integrates the identified alternate energy sources and other relevant components such as energy storage systems and backup power sources. The objective is to create an optimized and cost-effective hybrid power system design.

4. To assess economic viability: Will conduct a comprehensive economic analysis of the modelled hybrid power system. It will evaluate the capital costs, operational costs, maintenance costs, and other financial aspects associated with the integration of alternate energy sources. The objective is to determine the economic feasibility and cost-effectiveness of the system.

5. To Optimize system performance: Aims to optimize the performance of the hybrid power system through iterative simulations and sensitivity analyses using the HOMER software. It will explore different scenarios, such as varying energy demand, fuel prices, and government incentives, to identify the most economically favorable configurations.

6. To compare with conventional power generation: Compare the economic performance of the hybrid power system with conventional power generation options, such as fossil fuel-based power plants. The objective is to demonstrate the potential cost savings and environmental benefits of utilizing alternate energy sources.

7. To provide recommendations: Based on the analysis and findings, it provides recommendations for the economic management of alternate energy sources for electric power generation. It will outline strategies to optimize the use of renewable energy, reduce costs, and maximize the financial benefits of implementing a hybrid power system.

he aims and objectives of this project aim to provide valuable insights into the economic management of alternate energy sources for electric power generation using the HOMER software, with the ultimate goal of promoting sustainable and cost-effective energy solutions.

1.4 Contribution to Project:

Project Contribution for "Economic Management of Alternate Energy Sources for Electric Power Generation Using HOMER Software":

1. Identification of Alternate Energy Sources: One of the key contributions of the project would involve researching and identifying suitable alternate energy sources for electric power generation. This could include renewable sources such as solar, wind, hydro, biomass, or geothermal energy. The selection of energy sources would be based on their availability, viability, and compatibility with the region.

2. HOMER Software Implementation: HOMER (Hybrid Optimization of Multiple Energy Resources) is a powerful software tool used for analyzing and optimizing hybrid renewable energy systems. A significant contribution would involve implementing HOMER software and utilizing its capabilities to simulate and model various energy system configurations.

3. System Optimization and Analysis: Using HOMER, the project would contribute by conducting thorough optimization and analysis of different energy system configurations. This includes determining the optimal combination of energy sources, sizing of components (such as solar panels, wind turbines, batteries, etc.), and designing the system to meet the electricity demand while minimizing costs and maximizing the use of alternate energy sources

4. Economic Evaluation: A major contribution would be evaluating the economic feasibility and viability of the proposed energy system configurations. This involves

considering factors such as capital costs, operation and maintenance costs, fuel costs (if applicable), and any potential government incentives or subsidies. The economic analysis would provide valuable insights into the financial implications of adopting alternate energy sources for electric power generation.

5. Sensitivity Analysis: Another significant contribution would be conducting sensitivity analysis using HOMER to assess the impact of various parameters on the overall system performance and economics. This would involve evaluating the sensitivity of the system to changes in factors such as energy prices, component costs, financing options, and system reliability. The results of the sensitivity analysis would help in understanding the robustness of the proposed energy systems and identifying key areas of focus.

6. Environmental Impact Assessment: Contributing to the project would involve assessing the environmental impact of the proposed alternate energy systems. This includes evaluating factors such as greenhouse gas emissions, air pollution, water usage, and land requirements associated with each energy source. The findings would help in understanding the environmental benefits of adopting alternate energy sources and making informed decisions.

7. Policy and Planning Recommendations: Based on the analysis and evaluation conducted throughout the project, a valuable contribution would involve providing policy and planning recommendations. This could include suggestions for renewable energy targets, incentives, regulations, and integration strategies that promote the economic management of alternate energy sources for electric power generation.

1.5 HOMER Software Description:

HOMER software is a techno-economic simulation tool for optimizing hybrid power systems. It is used by more than 250,000 system designers and developers in over 190 countries to design hybrid microgrids or distributed generation systems. HOMER software combines engineering and economics in one powerful model, allowing users to determine the least-cost options quickly and efficiently. HOMER Pro is a microgrid software by HOMER Energy that is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. It features a new optimization algorithm that significantly simplifies the design process for identifying least-cost options for microgrids or other distributed generation electrical power systems.

Hybrid Optimization of multiple energy resources (HOMER) is an application created by the United States National Renewable Energy Laboratory [7]. The HOMER was first created in 1993. HOMER is a simulation system at its core. The HOMER will seek to model a feasible system for all potential equipment combinations to be found. HOMER can model hundreds or even thousands of systems depending on the questions. All simulations are followed by the optimization step.

The simulated structures are sorted by the parameters that identifies and filters to see the best suits. Although HOMER is basically an economic optimization system [7]. the input data for HOMER software are electrical load, resources and components costs, while at the output the following are obtained: net present cost (NPC), the cost of energy (COE), excess energy fuel consumption, and renewable energy used. The HOMER software performs the optimization considering a significant number of feasible combinations of the inputs' values as possible solutions, so the calculation times may be too large.

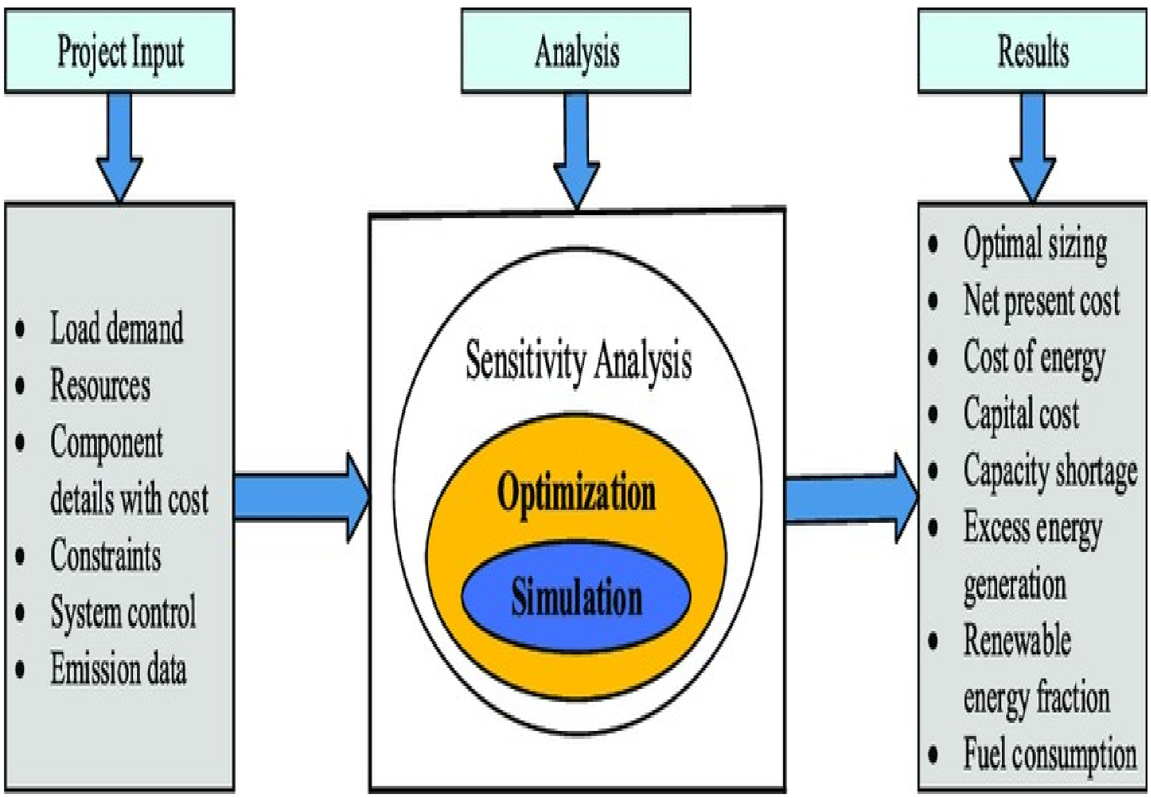

Fig. No. 1: Homer System block diagram

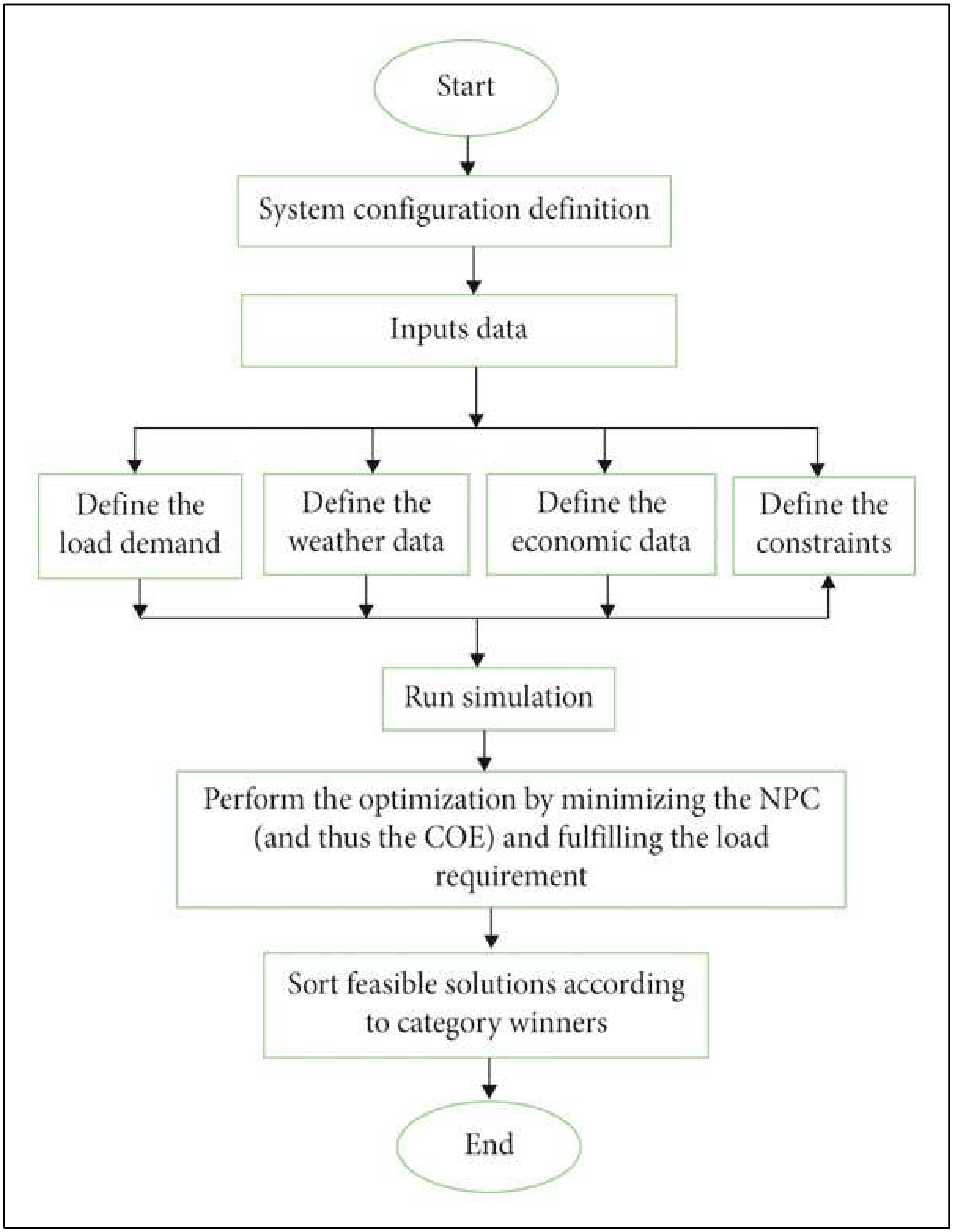

Fig. No.2: Homer Algorithm

CHAPTER 2: LITERATURE REVIEW

2.1 Historical Background

In recent decades, there has been a significant shift towards renewable energy sources such as solar, wind, and hydropower due to concerns over climate change and the depletion of fossil fuel reserves. Hybrid energy systems, which combine multiple renewable energy sources with conventional power generation or energy storage, have emerged as a viable solution to address the intermittency and variability of renewable energy generation.

The HOMER (Hybrid Optimization Model for Electric Renewable) software, developed by the National Renewable Energy Laboratory (NREL), has played a crucial role in the economic analysis of hybrid energy systems. It is a powerful tool that enables researchers, engineers, and decision-makers to assess the economic viability and optimal design of these systems.

Over the years, the software has undergone significant developments, incorporating more sophisticated algorithms and features to improve its accuracy and usability. The economic analysis provided by HOMER includes considerations such as equipment costs, fuel prices, operation and maintenance expenses, and other financial parameters. It helps stakeholders make informed decisions about the feasibility, profitability, and sustainability of hybrid energy projects.

The historical background of economic analysis for hybrid systems using HOMER software reflects the ongoing efforts to advance renewable energy technologies and optimize their integration into existing power systems. By providing a comprehensive and reliable platform for economic assessment, HOMER has contributed to the wider adoption and implementation of hybrid energy systems worldwide, promoting a more sustainable and greener future.

2.2 Literature Review:

[1] "Economical Analysis of Hybrid Energy Systems for Rural Electrification Using HOMER" [2017]

• Designing a stand-alone hybrid PV/Wind/Diesel/Battery System minimizing the cost of energy (COE), Co2 emission using HOMER software.

• Hybrid combination of renewable energy sources at an off-grid location can be a cost-effective alternative to grid extension and it is sustainable, economically, and environmentally friendly.

•Three combinations of hybrid system are proposed namely 1) PV/Diesel Generator/Battery/Power Converter. 2)PV/Wind/Diesel Generator/battery/power converter, and 3) PV/Wind/Diesel Generator/battery/power converter.

Review: From this paper we understand the basics of HOMER its different parameters and their meaning. Such as Net Present Cost (NPC), Cost of Energy (COE), Yearly Operating Cost.

[2] "Technical Performance Evaluation and Economic Viable Solutions Using Hybrid Renewable Energy Systems" [2015]

• The design of a hybrid renewable energy system with battery backup has been proposed in this paper. For this hybrid system, the meteorological data of Solar Radiation, and hourly wind speed are taken to meet the primary load of 100KWh/day, and 28Kw peak load.

• The local solar radiation, wind data, and load were analysed and simulated in HOMER to assess the technical and economic viability of the integrated system.

• Simulation of this hybrid power system was done using HOMER.

Review: This paper presents a study of a large electric load system. It is observed that the in this case the combination of a wind turbine(10kw), a Diesel generator(15kw) and a minimum of 60 batteries is economically most feasible with a Cost of Energy (COE) $0.612/Kwh.

[3] "A Review of Hybrid Renewable/Alternative Energy Systems for Electric Power Generation: Configuration, Control, And, Applications [2017]"

• Different coupling methods for the integration of different RE/AE systems such as DC coupling and AC coupling are discussed in this paper.

• In DC coupling, the dc sources may be connected to the DC bus directly if appropriate. If there are any dc Loads, they can also be connected to the DC bus directly or through DC/DC converters.

• In AC coupling there are two types such as power frequency AC coupling (PFAC) and high-frequency AC coupling (HFAC).

Review: In this paper, we studied what is hybrid system is and its benefits over the conventional energy system and single renewable energy source-containing systems.

[4] "Design of hybrid power systems using Homer simulator for different renewable energy sources" [2017]

• The HOMER is a software tool developed by the National Renewable Energy Laboratory to design hybrid systems such as renewable microgrids, standalone, or grid-connected hybrid power systems.
• Three cases are studied including 1) PV- Battery, 2) Wind turbine- Battery, and 3) PV-Wind turbine-Battery and their economic and technical parameters were analysed in Homer.
• The 3rd case (PV-Wind turbine-Battery) is more economical in terms of power generation than other cases.

[5] "Optimization and operation of a renewable energy-based PV-FC-Micro grid using HOMER" [2017]

• This paper optimizes the operation of PV/FC systems with storage devices under DC grid-connected mode and provides simulation results.

• HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate possible design configurations.

Review: From this paper, we understand the working of fuel cells in HOMER. Understand how to use a fuel cell in HOMER. The addition of a hydrogen fuel cell requires an electrolyser and hydrogen storage tank. Add a generator and change its fuel to Stored Hydrogen.

[6] "Design and Economic Analysis of Hybrid Renewable Energy System" [2019]

• The focal point of this paper is to design and perform analysis along with cost analysis of a wind-solar on-grid hybrid power generation system for a selected location.

• For modelling of the proposed hybrid system MATLAB-SIMULINK is used and the Hybrid optimization model of renewable energy (HOMER) is used for cost analysis.

This paper conducts a feasibility analysis to explore the potentialities of green energy in Bangladesh. design and analyze the performance of our proposed model using simulation tools to analyze an on-grid model. This model does not require any extra, large battery bank for storage of power in normal operation. Initially, this research work carries out investigating the potentialities of green energy at various locations of Bangladesh, particularly Mymensingh, Mirzapur, Rajshahi, Chottogram, and Kutubdia. Then considering the various parameters like component specification with their cost, and financial aspects with ideal values, we finalize the proposed location to be Mymensingh and simulation works are carried out.

By analysing the simulation result, it is found that the proposed 4 MW hybrid model with 94% renewable fraction is most suitable for Mymensingh. It can also be concluded that the proper utilization of renewable energy reduces a large amount of emissions in the atmosphere. After designing our proposed HRES model by HOMER for cost analysis it found that the output power price is 7.67 taka per kWh, which is economic as there is no need of any fuel for producing power. Therefore, it can be said that the proposed grid connected “HRES” system is most suitable cost-effective as it offers several benefits. For future work we aim for a dynamic analysis with detail models of the RE resources, which can be conducted along with the application of different types of scenarios of fault situations.

CHAPTER 3: SYSTEM CONFIGURATION

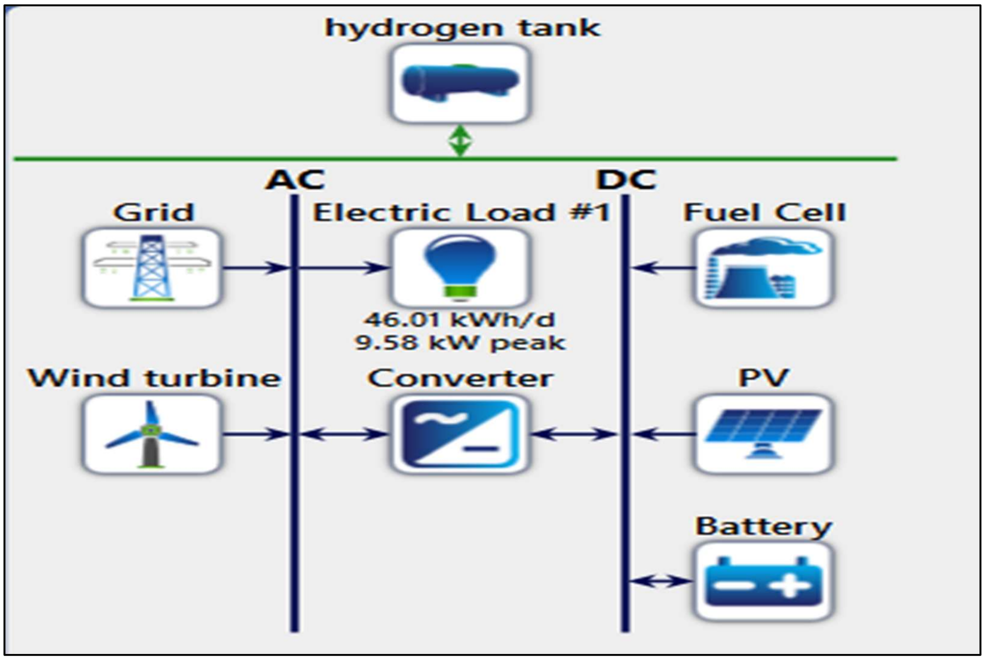

Fig. No3: System Schematic Diagram

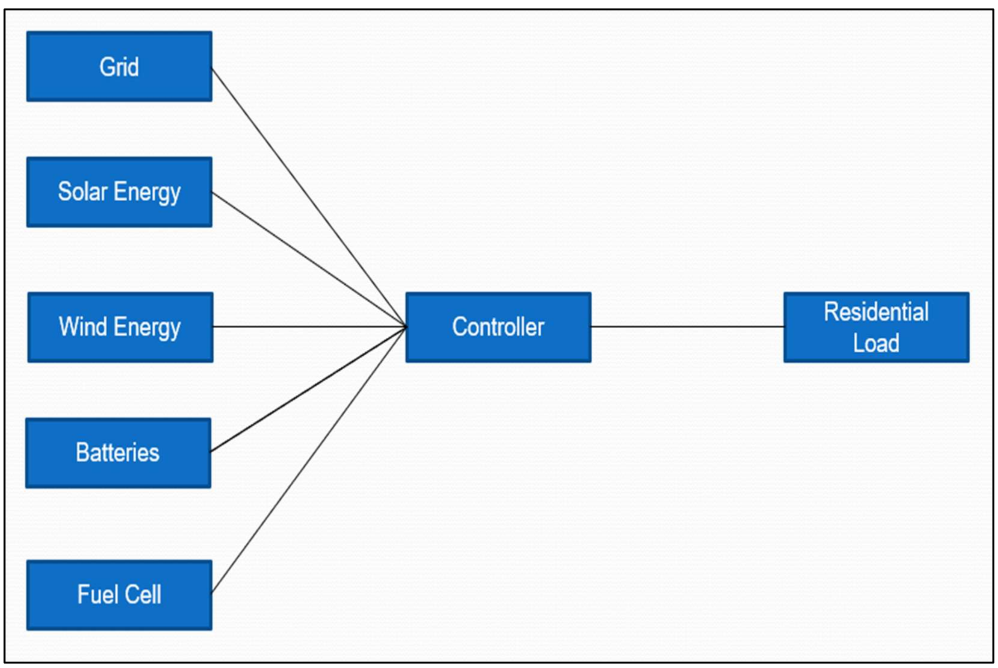

Fig. No.4: System Block Diagram

CHAPTER 4: METHODOLOGY

The methodology for this paper involves software based apprach. First the Electric Load data is obtained including average daily consumption(in KWh) and peak load (Kw) and daily load profile is ploted with time frame of 60 minutes.

Here the average daily consumption is 46.01 KwH with a peak of 9.58kw. The type of load is residential load. The cost of one unit(KwH) is 11.86(including all taxes). The simulation is performed on Homer by giving inputs such as component rating and costing. The simulation is done for given system component ratings and then homer optimization analysis is done.

This, paper adopts software-based approach as its technique. Daily load profile is obtained, the electric load data, which includes average daily consumption (in KWh) and peak load (in Kw), gathered. With a peak of 9.58 kw, the average daily consumption at this site is 46.01 KwH. Residential load is a specific type of load. One-unit (KwH) costs 11.86 (all taxes included). Simulation is performed on HOMER, which executes using inputs like component ratings and costing. By performing the simulation for the specified system component ratings, homer optimization analysis is carried out.[3]

4.1 Metrological Data Collection:

Climate details including wind velocity and PV radiation used for this study have been collected from the National Aeronautics and Space Administration (NASA). According to NASA, monthly averaged global solar radiations for sites were collected over 22 years. The wind speed data are recorded for 30 years.

Table.1 shows the Monthly Average Solar Irradiance Data (KWh/m^2/day) and Clearness Index data at a given location.

Table.2 shows the data of the Monthly Average Wind Speed (m/sec). This data is used as input to Homer software to perform a simulation for the output power of solar PV and Wind turbines.

Table 1: Wind Data

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed(m/sec)	4.330	4.410	4.440	4.510	5.490	6.970	8.480	7.660	5.050	4.430	4.810	4.740

Table 2: Solar radiation

Month	Clearness index	Daily Radiation (Kwh/m^2/day)
Jan	0.659	5.080
Feb	0.665	5.750
Mar	0.665	6.480
Apr	0.651	6.860
May	0.605	6.570
Jun	0.398	4.340
Jul	0.325	3.520
Aug	0.336	3.560
Sep	0.449	4.480
Oct	0.571	5.110
Nov	0.632	4.990
Dec	0.642	4.740

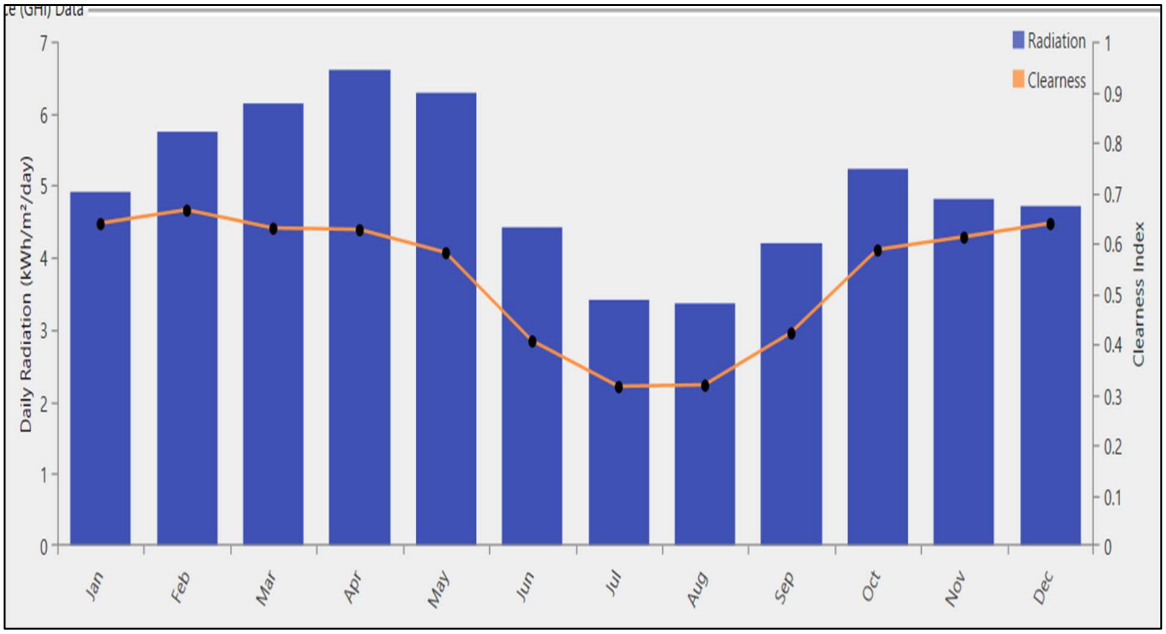

Fig. No.5: Solar clearness index Data

4.2 Electric Load Collection

To calculate electric load data for a house, using the following steps:

1. Identify Electrical Appliances: Make a list of all the electrical appliances and devices present in the house. Include items such as lighting fixtures, heating and cooling systems, kitchen appliances (refrigerator, oven, microwave), entertainment devices (TV, stereo, gaming consoles), and any other electrical equipment.

2. Determine Power Ratings: Find the power rating or wattage for each appliance. It usually finds this information on product labels or in the user manual. The power rating is typically indicated in watts (W) or kilowatts (kW).

3. Estimate Daily Usage: Estimate the average daily usage duration for each appliance. This can be based on typical usage patterns or by referring to the appliance's specifications. For some appliances, it may use them continuously, while others may be used for shorter periods.

4. Calculate Daily Energy Consumption: Multiply the power rating of each appliance by its daily usage duration to calculate the daily energy consumption for that appliance. This will give the energy consumed by each appliance in kilowatt-hours (kWh) per day.

5. Sum Up the Load: Add up the daily energy consumption values for all the appliances to get the total daily load for the house. This will represent the total energy consumed by all the electrical devices in the house on its daily basis.

6. Consider Seasonal Variations: Keep in mind that the electric load can vary based on the season. For example, during summer, the load may be higher due to air conditioning usage, while winter may see increased usage of heating systems. Adjust the load calculations accordingly to account for seasonal variations.

7. Analyze Peak Loads: Identify any appliances or activities that result in high peak loads, such as using multiple high-power devices simultaneously. Consider the simultaneous usage of appliances when calculating peak loads, as it can affect the sizing of electrical infrastructure, such as circuit breakers and wiring.

8. Verify with Electricity Bills: It cross-check the load calculations by comparing them with the electricity bills. The bills typically indicate the total energy consumed in kilowatt-hours (kWh) over a specific billing period. Ensure that calculated load aligns with the energy consumption mentioned in the bills.

The load connected to the system is 46.01 kW/day, with a peak load of 9.58 kW. For this simulation analysis, the daily load profile is calculated for a time interval of 60min for a single day in all months. Below is the daily, seasonal, and yearly load profile of the given load.

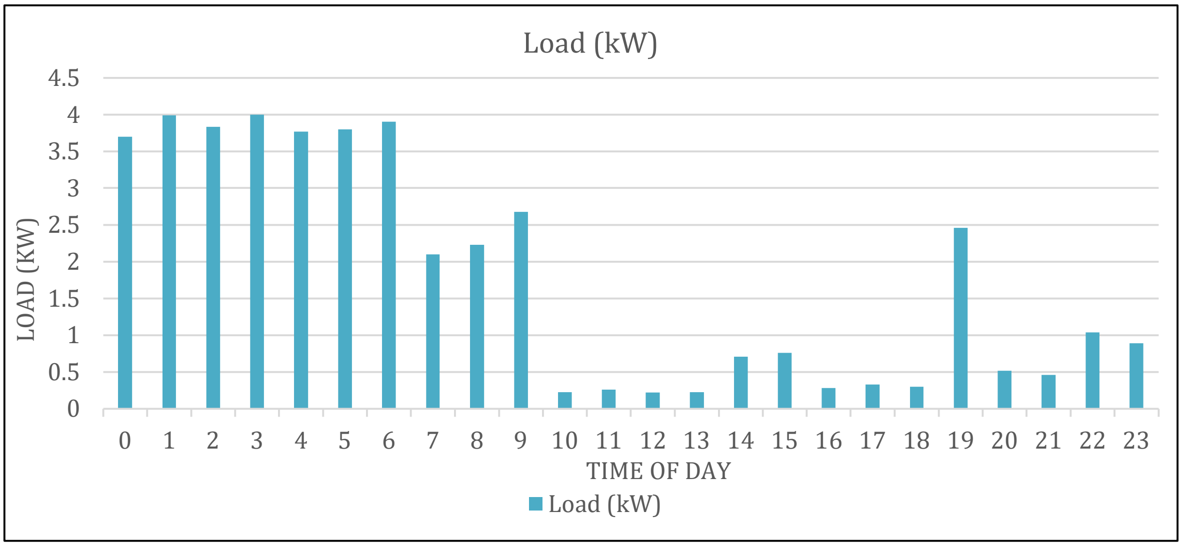

Fig. No.6: Daily Electric Load Data (kWh)

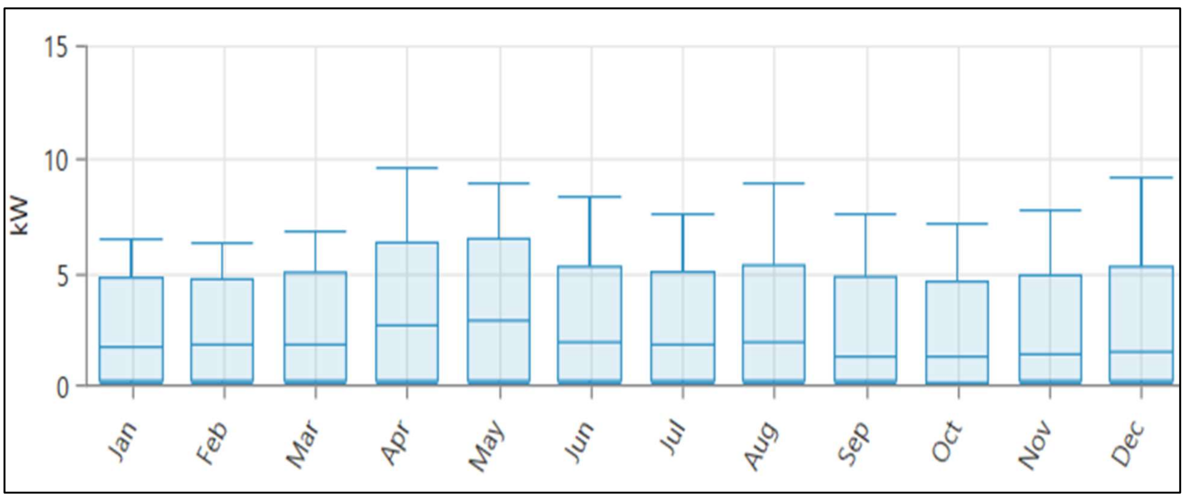

Fig. No. 7: Annual and Seasonal Electric Load Data (kWh)

4.3 System Components and Configuration:

Table 3: Electric Component rating and Costing

Component Name	Rating (Kw)	Cost (Rs.)
Solar PV + other required components	1 Kw (4no. 250w solar panels)	32000
Wind Turbine	1.5	260000
Single phase inverter	7.5	125000
Batteries (Lead Acid)	12 v, 200A (10 no.)	110000

4.4 Mathematical Modelling of System Components:

a) Solar PV system:

Homer uses the following equation to calculate the output of Solar PV.

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

Where,

Y_{PV}	= the rated capacity of the PV array, meaning its power output under standard test conditions [kW]
f_{PV}	= the PV derating factor [%]
$\overline{G}_T$	= the solar radiation incident on the PV array in the current time step [kW/m^2]
$\overline{G}_{T,STC}$	= the incident radiation at standard test conditions [1 kW/m^2]
α_P	= the temperature coefficient of power [%/°C]
T_c	= the PV cell temperature in the current time step [°C]
$T_{c,STC}$	= the PV cell temperature under standard test conditions [25°C]

b) Wind Turbine:

1. Wind Resource Assessment: The first step is to assess the wind resource at the project site. This involves gathering data on wind speed, direction, and other relevant parameters over a significant period. HOMER may use historical wind data or user-provided inputs for this assessment

2. Power Curve: A power curve is a relationship between the wind speed and the power output of a wind turbine. It is typically provided by the turbine manufacturer and represents the turbine's performance characteristics. HOMER may use this power curve as a reference for its calculations.

3. Wind Speed Distribution: Based on the wind resource assessment, HOMER determines the frequency or probability distribution of wind speeds at the site. This distribution provides information on the likelihood of wind speeds occurring at different levels.

4. Power Output Calculation: Using the wind speed distribution and the power curve, HOMER estimates the power output of the wind turbine. It does this by multiplying the power output corresponding to each wind speed by the probability of that wind speed occurring. The sum of these products provides an estimate of the average power output.

5. Losses and Adjustments: HOMER may consider various factors that affect the actual power output of a wind turbine, such as losses due to mechanical inefficiencies, electrical losses, and availability. It may also account for any adjustments or constraints specified by the user, such as turbine derating factors or downtime for maintenance.

6. Energy Production Analysis: HOMER aggregates the estimated power outputs over a specific time period (e.g., hourly, monthly) to calculate the total energy production of the wind turbine. This analysis helps evaluate the overall performance and suitability of the wind turbine in the context of the hybrid renewable energy system.

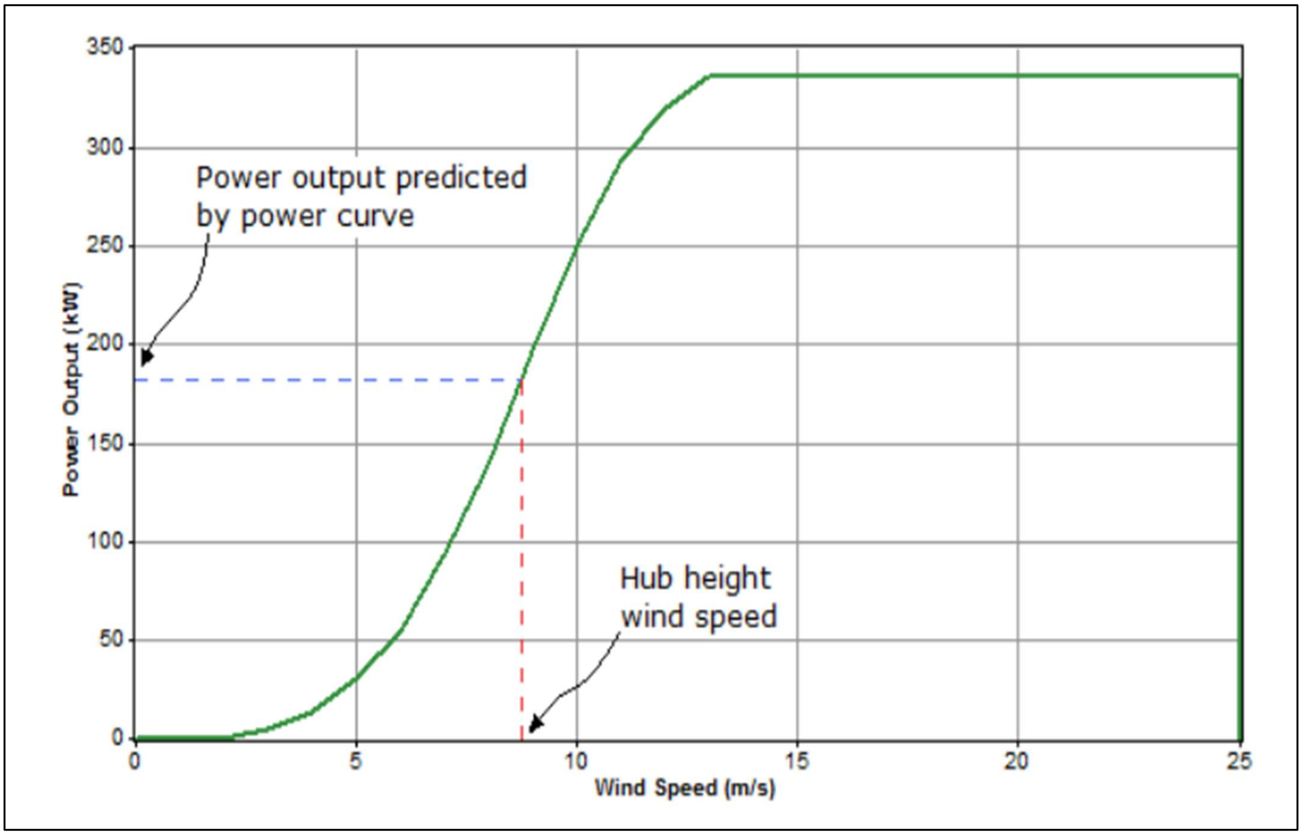

Fig. No. 8: Wind Turbine Power Curve

c) Hydrogen Fuel Cell (PEM Type):

Hydrogen has an energy density of approximately 120MJ/kg, almost three times more than diesel or gasoline. FC appears today in several configurations, operating on different electrolytes and presenting different power ranges, efficiencies, and operation characteristics. Proton Exchange Membrane (PEM) FC poses a good start-up and shut-down performance.

It may be the most suitable choice among all kinds of FCs. The fundamental structure of a PEM FC can be represented as two electrodes (anode and cathode) separated by a solid membrane. Hydrogen fuel is fed continuously to the anode and air is fed to the cathode. The overall chemical reaction is as follows:

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O \text{ ....(1)}$$

The Hydrogen consumption at rated power P_{FC} Kw of FC in 1 Hr. can be calculated by

$$HY_{FC} = \frac{Pfc*3600}{2*Vfc*F} \text{ (mol/h}^{-1}\text{)}\ldots\ldots.(2)$$

The following are the main components of a Hydrogen Fuel Cell (PEM Type)

i) Electrolyzer:

Hydrogen can be produced by the decomposition of water into its elementary components by passing the electric current. A water electrolyzer consists of several cells connected in series. Two electrodes of the electrolyzer are separated by an aqueous electrolyte or solid polymer electrolyte. Electrical current through the electrolyzer enables the decomposition of water into hydrogen and oxygen. This process can be expressed by.

$$H_2O + \text{electricity} \rightarrow H_2 + 1/2\ O_2 \ \ldots\ldots\ldots\ldots.(3)$$

ii) Hydrogen Tank:

Primarily, there are three different methods with variable characteristics for hydrogen storage: metal hydrides, liquefaction, and high-pressure compression. As a general guideline, hydrides are suitable for small quantities of H_2 (e.g., in the range of 1Kg) ad when a high safety factor is required. Liquid H_2 is advantageous with regard to space required and safety issues. The compression tank storage is the least complex storage type as compared to the other two.

4.5Economic Terms:

A) Net Present Cost (NPC):

The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime. HOMER calculates the net present cost of each Component in the system, and of the entire system.

B) Levelized Cost of Energy (LCOE):

It is an output variable. HOMER defines the levelized cost of energy as the average cost per kWh of useful electrical energy produced by the system. The symbol of this parameter is COE. And the unit is Rs. /kWh.

To calculate the COE, HOMER divides the annualized cost of producing electricity by the total electric load served.

C) Return on Investment (ROI):

The Return on Investment (ROI) is the yearly cost savings relative to the initial investment. The ROI is the average yearly difference in nominal cash flows over the project lifetime divided by the difference in capital cost.

HOMER calculates the return on investment with the following equation:

$$ROI = \frac{\sum_{i=0}^{R_{proj}} C_{i,ref} - C_i}{R_{proj}(C_{cap} - C_{cap,ref})}$$

where:

$C_{i,ref}$	= nominal annual cash flow for base (reference) system
C_i	= nominal annual cash flow for current system
R_{proj}	= project lifetime in years
C_{cap}	= capital cost of the current system
$C_{cap,ref}$	= capital cost of the base (reference) system

C) Simple Payback Period:

HOMER software provides the calculation of the simple payback period as one of the economic metrics for evaluating the financial performance of an energy system. The simple payback period represents the time it takes for the cumulative savings or benefits from the system to equal the initial capital cost. It is a measure of how quickly an investment in the energy system can be recovered.

D) Operating Cost:

In HOMER software, the operating cost refers to the expenses associated with the operation and maintenance of the energy system being analyzed. It includes the ongoing costs required to ensure the system's functionality and efficiency over its operational lifespan.

The operating cost of system can include several components, such as:

1. Fuel Costs: If the energy system includes conventional generators that rely on fuel sources like diesel, natural gas, or gasoline, the operating cost will include the expenses related to purchasing and using the fuel. HOMER allows the input the fuel price and calculate the associated fuel costs based on the system's fuel consumption.

2. O&M (Operation and Maintenance) Costs: These costs encompass routine maintenance, repair, and replacement of components in the energy system. It includes expenses for servicing equipment, conducting inspections, and replacing parts or components as they wear out or become obsolete. HOMER allows the specify the O&M costs for different components, such as generators, batteries, inverters, etc., either as a fixed value or as a percentage of the initial capital cost.

3. Battery Degradation Costs: If the system includes battery storage, HOMER considers the degradation of battery capacity over time. As batteries age, their capacity to store energy gradually decreases. The software incorporates this degradation and calculates the costs associated with battery replacement or refurbishment, considering the reduced storage capacity.

4. Grid Costs: If the system is connected to the grid, there might be costs associated with grid connection or purchasing electricity from the grid when the system cannot meet the load demand. HOMER allows to include the grid costs as part of the operating cost analysis.

CHAPTER 5: SIMULATION AND RESULTS

5.1 Results without performing HOMER Optimization:

Case I) Only Grid (220V, 50Hz):

Table 4: Performance parameters (Case I)

Energy purchased (KwH)	16794 kwh
Operating Cost (Rs.)	199172
Total NPC (Rs.)	2574808
Energy Sold back (KwH)	0
Renewable %	0
COE (Rs.)	11.86

Case II) Grid (220V, 50Hz): + Solar PV (1kW):

The cost of a 1 KW solar power system is 157000Rs, Including 4no. of 250W solar panels of total cost 27000Rs, 7.5Kw single phase inverter of cost 125000Rs, and other components of cost 5000. The lifetime of Inverter is considered for 10 years.

Table 5: Performance parameters (Case II)

Energy purchased (KwH)	15603 kwh
Operating Cost (Rs.)	178621
Total NPC (Rs.)	2466131
Energy Sold back (KwH)	542 kwh
Renewable %	10%
COE (Rs.)	11

Case III) Grid + Solar PV unit + Wind turbine unit:

The cost of a 1.5 wind turbine unit is 180000 including converters and wiring. The total cost of this system is 337000Rs. The maintenance cost of the wind turbine is of 5000Rs. /year.

Table 6: Performance parameters (Case III)

Energy purchased (KwH)	13538 kwh
Operating Cost (Rs.)	144901
Total NPC (Rs.)	2210210
Energy Sold back (KwH)	1742 kwh
Renewable %	27%
COE (Rs.)	9.22

Case IV) Grid + Solar PV + Wind turbine + Hydrogen Fuel Cell:

The cost of a PEM type hydrogen cell unit is 300000 Rs. The total cost of this configuration is 637000 Rs. 100kg

Table 7: Performance parameters (Case IV)

Energy purchased (KwH)	12915 kwh
Operating Cost (Rs.)	145115
Total NPC (Rs.)	2120496
Energy Sold back (KwH)	1101 kwh
Renewable %	27.8
COE (Rs.)	10.86

Case V) Grid + Solar PV + Wind Turbine + Hydrogen Fuel Cell + Batteries:

The Cost of 10 no. of 12v 200Ahr Batteries is 110000 in total including their wiring and mounting structure cost. In this project lead acid batteries are used for the purpose of excess-produced energy storage. Therefore, the total cost of this configuration is 747000 Rs. The lifetime of each lead acid battery is considered to be 5 years with a replacement cost of 33000 Rs. (30% of purchasing cost).

Table 8: Performance parameters (Case V)

Energy purchased (KwH)	12907 kwh
Operating Cost (Rs.)	150200
Total NPC (Rs.)	2688712
Energy Sold back (KwH)	1107 kwh
Renewable %	27.9%
COE (Rs.)	11.60

Production	kWh/yr	%
1kw Solar Pv Emulator(stage 2)	1,589	8.24
Fuel Cell	1,299	6.74
1.5kW Wind Turbine(stage 2)	3,488	18.1
Grid Purchases	12,907	66.9
Total	19,284	100

Fig. No. 10: Performance parameters (Case V)

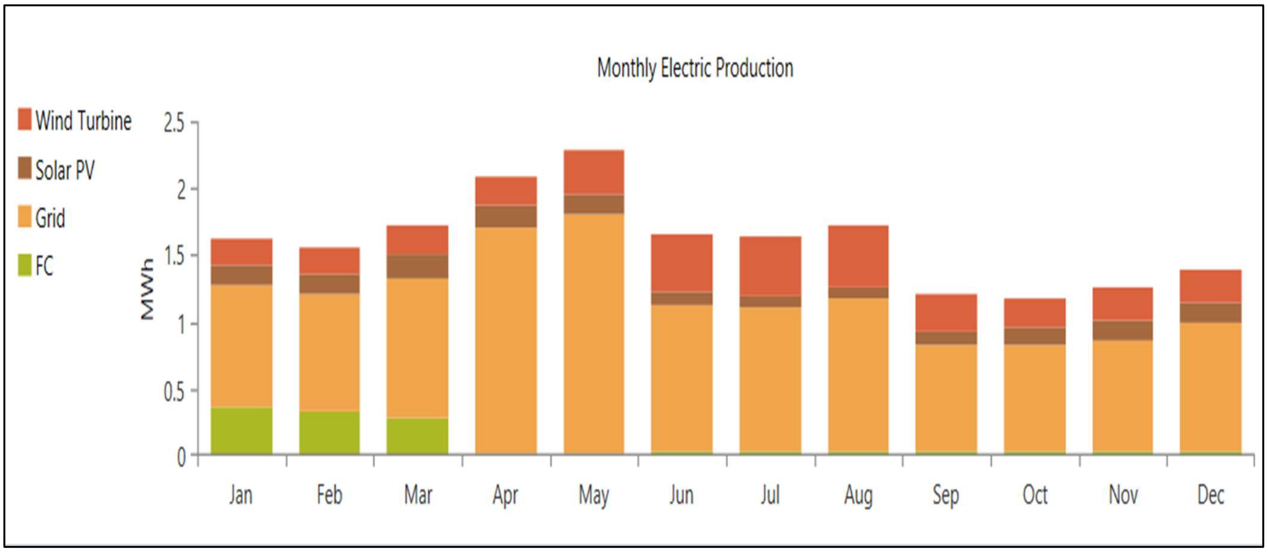

Fig. No. 9: Component-wise yearly electrical production
(CASE V)

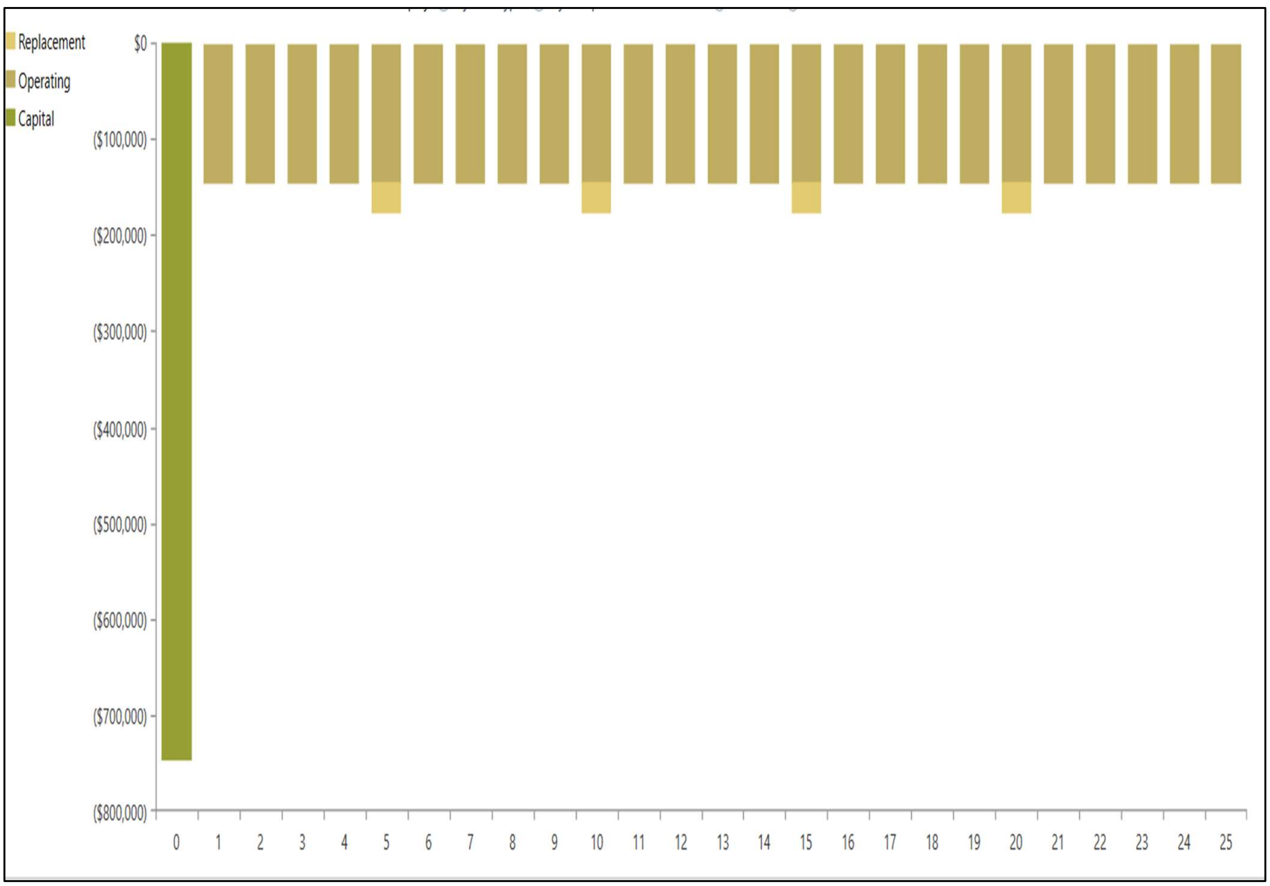

Fig. No. 11: Cash Flow of (Case V)

5.2 System Result with HOMER Optimization:

For performing the optimization analysis, the range of solar PV system is taken between 1 to 3kw, the wind turbine range is taken between 0 to 1.5kw, Batteries (0 to 10no.), and the range of hydrogen fuel cell is between 0 to 500 watt.

According to HOMER optimization analysis, the optimum system satisfying the load and economic parameters is of a configuration comprising 3kw solar PV, 1kw wind turbine system and 2.46 kw inverter. The initial capital of this configuration is Rs. 317000, with an operating cost of Rs. 109220.

Production	kWh/yr	%
1kw Solar Pv Emulator(stage 2)	4,768	22.7
1.5kW Wind Turbine(stage 2)	3,488	16.6
Grid Purchases	12,772	60.7
Total	21,028	100

Fig. No. 12: Component-wise % energy sources of optimized

Economic Metrics

IRR	28%
ROI	24%
Simple Payback	3.5 yr

Fig. No. 13: Economic parameter of Optimized system

Table 9: Comparing Performance parameters (all optimized cases)

Sr. No.	System Configuration	NPC (Rs.)	Operating Cost (Rs. /year)	Initial Capital (Rs.)	Renewable Sources Percentage (%)	Energy Purchased (kWh)	Energy Sold (kWH)
1	G+ PV (3Kw) + W (1 Kw) +I (2.46 kW)	17,28,936	6.43	3,16,991	38.5317	12771.86	3984.332
2	G + PV (3kW) + W (1 kW) + I(2.46kW) + B (1)	17,46,601	6.50	3,28,538	38.5488	12769.68	3986.567
3	G+ PV (3kW) + I (2.46 kW)	20,19,016	8.11	1,36,887	23.4872	14717.51	2441.718
4	G + PV (kW) + I (2.46 kW) + B (1)	20,36,571	8.18	1,48,069	23.5008	14715.34	2442.301
5	G + W (1 KW)	22,84,719	10.01	1,80,000	19.7653	14157.56	851.5541

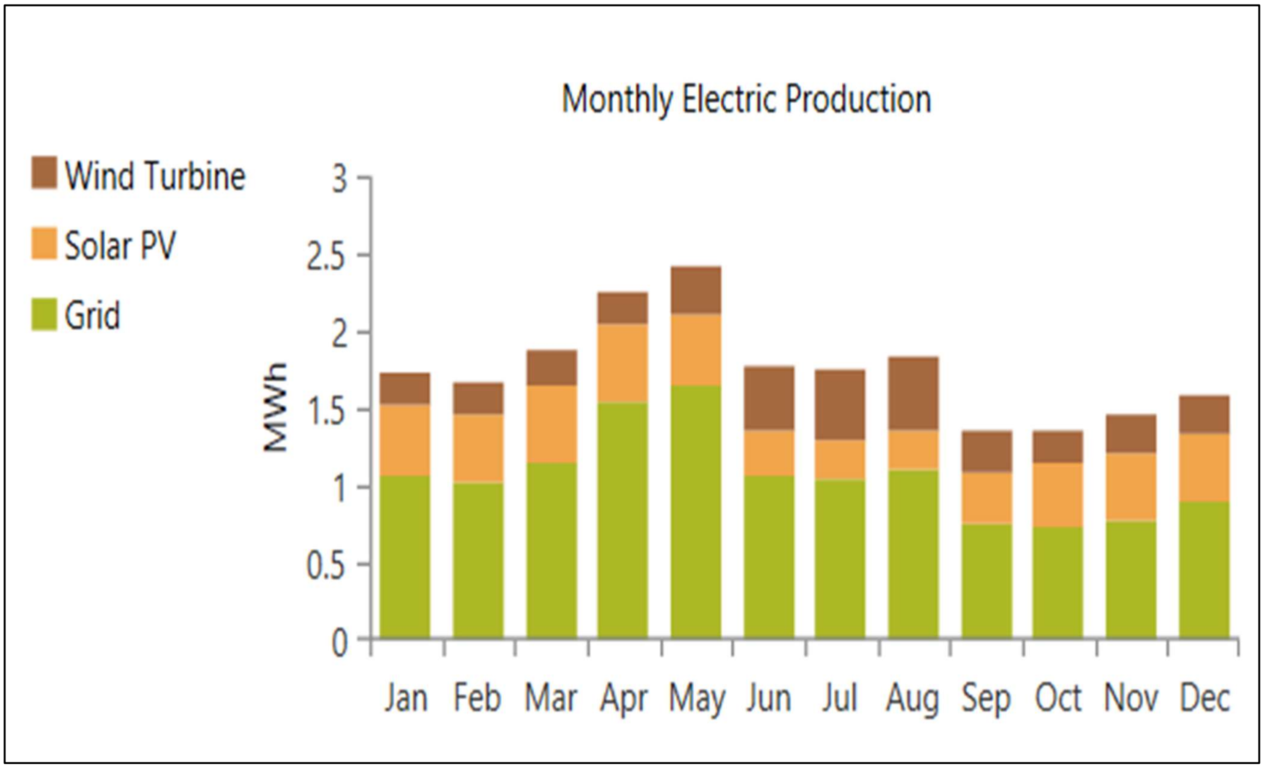

Fig. No. 14: Yearly Electrical production (optimized system)

CHAPTER 6: CONCLUSION AND DISCUSSION

6.1 Conclusion:

The simulation study of a hybrid energy system comprising alternative energy sources is carried out. By comparing the different cases of simulation results without HOMER optimization It is observed that case III has the lowest operating cost (Rs. 1,44,901) with a COE of Rs. 9.22. The initial cost of case III configuration is Rs. 3,37,000.

The case V is an actual system that is going to install, the initial cost of this system is 7,47,000Rs. With an operating cost of 1,50,200 Rs the annual saving, in this case, is Rs. 48,972. The payback period for this case V is of 15 years (operating cost/annual saving). The system is cost-saving but not that economically good.

HOMER optimization simulation is performed to get an optimized system configuration for this configuration we give several limits to Homer for a rating of sources which is feasible for us to install. This is the case VI system. HOMER simulated 19444 feasible cases for system configuration and give the system comprising 3kw solar PV, 1kw wind and an inverter of 2.46kw as the optimum system with an initial capital requirement of Rs. 3,16,992. The yearly operating cost of this system is Rs. 109220, and the annual saving in the energy bill, in this case, is Rs. 89995. The payback period for this system is of 3.5 years. The share of renewable sources in this system is 38.5 %. The NPC (Net Present Cost) of this optimized system is Rs. 17,28,936.

Therefore, from simulation study and comparing results it is observed that the HOMER-optimized system is more economical than our actual system (Case V) in terms of cost of energy (COE) and NPC. Hence, it is good to perform the HOMER simulation to check the system's feasibility economically and technically before making an investment in hybrid system projects. Below is a chart of the cash flow of the base system and lowest cost system (HOMER optimized system) plotted across the project lifetime.

Table 10: Comparison of Actual system and optimized

Comparing Parameters	System as it is without optimization	HOMER optimized System
Energy purchased (KwH)	12,907 kwh	12,770 kwh
Operating Cost (Rs.)	1,50,200 Rs.	1,09,220 Rs.
Total NPC (Rs.)	26,88,712	17,28,936
Energy Sold back (KwH)	1,107 kwh	3,984 kwh
Renewable %	27.9%	38.5%
COE (Rs.)	11.60	6.44

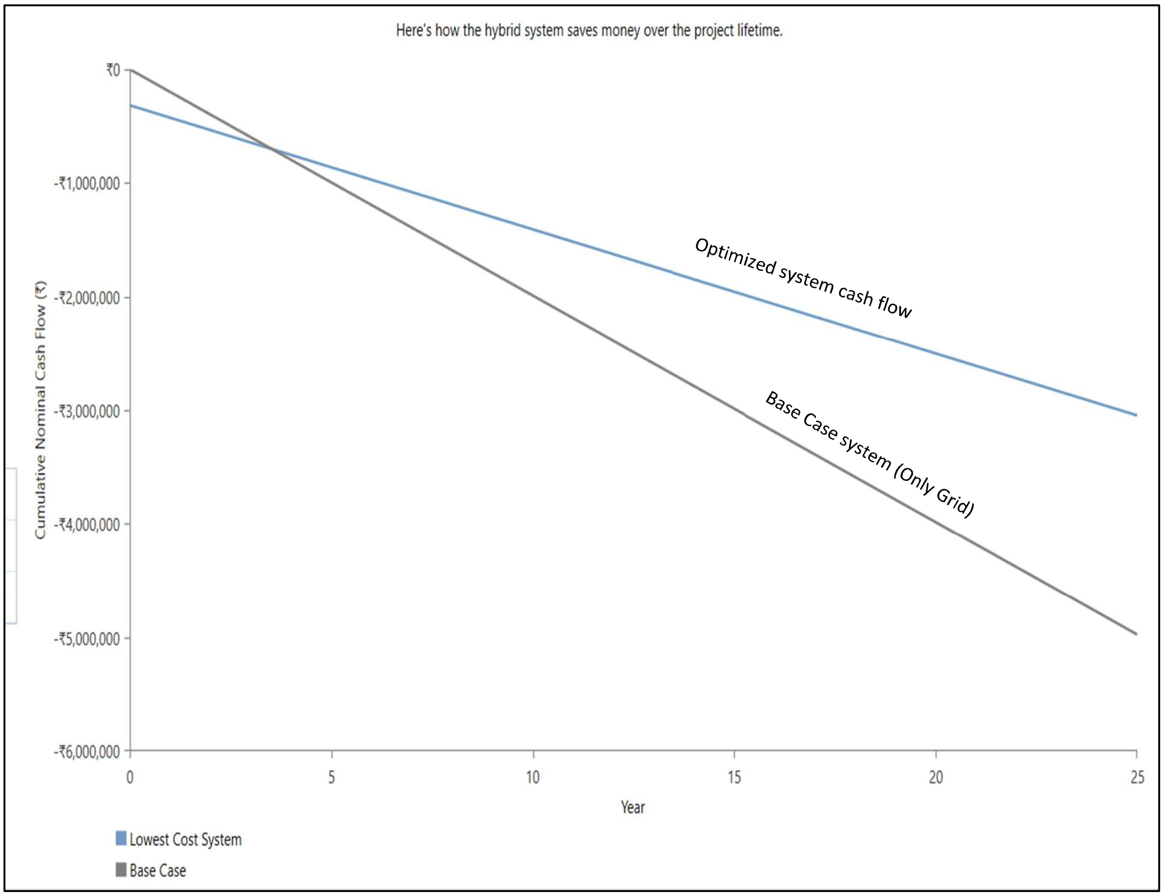

Fig. No. 15: Cash Flow Comparison of Base case (only grid) and optimized case

CHAPTER 7: FUTURE SCOPE

7.1 Future Scope

1. Advancements in renewable energy technologies: As new and more efficient renewable energy technologies emerge, such as advanced solar panels, wind turbines, and energy storage systems, integrating these technologies into hybrid systems will become more economically viable. The economic analysis using HOMER software can help assess the feasibility and optimize the performance of these advanced hybrid systems.

2. Grid integration and smart grid applications: Hybrid systems can play a crucial role in grid integration, especially in regions with intermittent renewable energy sources. HOMER software can analyze the economic viability of hybrid systems that integrate with the existing power grid, considering factors like grid stability, power quality, and potential revenue streams from grid services.

3. Microgrids and remote/off-grid applications: Hybrid systems using renewable energy sources can provide reliable and affordable power in remote areas or off-grid locations. The economic analysis with HOMER software can help design optimal hybrid systems for microgrids, considering factors like load demand, resource availability, and cost-effectiveness.

4. Energy management and optimization: HOMER software can be further enhanced to provide advanced energy management and optimization capabilities for hybrid systems. This includes optimizing the operation and scheduling of different energy sources, storage systems, and backup generators to minimize costs and maximize system efficiency.

5. Policy and regulatory support: Economic analysis using HOMER software can aid policymakers and regulators in evaluating the economic viability of hybrid systems and formulating effective policies and incentives. This can help promote the adoption of hybrid systems at both the individual and industrial levels, fostering sustainable energy development.

6. Techno-economic analysis for large-scale applications: While HOMER software has been primarily used for small to medium-scale hybrid systems, there is potential for its application in large-scale projects, such as utility-scale hybrid power plants or industrial microgrids. Future developments could focus on adapting HOMER for larger systems and incorporating relevant economic factors specific to these applications.

7. Integration of machine learning and AI: By integrating machine learning and AI algorithms, HOMER software can improve its predictive capabilities, optimize system design, and control strategies, and enhance economic analysis.

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Annexures:

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Akshay Babanrao Malangner,

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