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RESEARCH ARTICLE

Optimization, Design, and Feasibility Analysis of a Grid-Integrated Hybrid AC/DC Microgrid System for Rural Electrification

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ABSTRACT Recently, a hybrid microgrid system is playing a vital role to supply sustainable power to remote areas using renewable energy sources. The main motto of this research is to design the optimal hybrid microgrid system by identifying the potentials of power production in selected location. The proposed design provides sustainable power to meet the different load demands of various communities in Doddipalli village, Chittoor, Andhra Pradesh, India. Here, a Hydrogen tank and hydrogen loads are also integrated with the grid-integrated hybrid microgrid system (GIHMGS) for hydrogen production with excess electricity for energy management strategies. Optimization process, techno-economic, and environmental analysis were carried out to construct the optimal system using HOMER software. The domestic average daily load demand is about 704.86 kWh/day. Homer software generates several possible designs, and the top eight are evaluated for use in the case studies. The optimal system (PV/WT/Grid) is decided by comparing the lowest levelized cost of energy ($0.0751/kWh/d), minimum net present cost ($6.92M) and the high renewable energy fraction (97.8%). The proposed design consists of solar photovoltaic (PV)-13.9 kW, wind turbine (WT)-800kW(4), hydrogen tank-10 kg, electrolyser-700 kW and power converter-94 kW. Based on the results, the proposed system has less carbon dioxide (CO_2) emission, making it better for the environment. In this research work, the optimal design would be more economical when solar PV, Wind Turbine became the primary energy sources. This analysis shows that proposed hybrid system can be an appropriate model to provide reliable power at a low generation cost for the considered area.

INDEX TERMS Solar photovoltaic, diesel generator, wind turbine, battery energy storage, grid, renewable energy sources, grid-integrated hybrid microgrid systems, minimum net present cost, lowest levelized cost of energy, high renewable energy fraction, homer software.

NOMENCLATURE

Abbreviations

Ah	Ampere hour.
AL	Agricultural Loads.
AC	Alternating Current.
A.P.	Andhra Pradesh.
Avg	Average.
AWS	Annual wind speed.
BS	Battery Storage.
CL	Commercial Loads.
CI	Clearness index.
CO_2	Corban dioxide.
CRF	Capital recovery factor.
CON	Converter.
DC	Direct current.
DL	Domestic Loads.
DG	Diesel generator.
EDCL	Electricity Distribution Company Limited.
E-53	Enercon-53.
EMS	Energy management system.
FC	Fuel Cell.
GA	Genetic algorithm.
GIHMGS	Grid-integrated hybrid microgrid system.

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HOMER	Hybrid optimization of multiple energy resources.
HH	Height of the hub.
HTank	Hydrogen tank.
HRES	Hybrid renewable energy systems.
km	Kilo meter.
LED	Light emitting diode.
LCOH	Levelized cost of hydrogen.
LCOE	Levelized Cost of Energy.
LPSP	Loss of power supply probability.
Lio-Ion	Lithium Ion.
ln	Natural logarithm.
Max.	Maximum.
Min.	Minimum.
MILP	Mixed-integer linear programming.
NPC	Net Present Cost.
NASA	National aeronautics and space Administration.
NREL	National renewable energy laboratory.
O&M	Operating and maintenance cost.
PERC	Passivated Emitter and Rear Cell.
PSO	Particle swarm optimization.
PSOCF	Particle swarm optimization algorithm with shrinkage factor.
PSOAIW	Adoptive inertia weight PSO.
PEV	Plug-in electrical vehicle.
PV	Photovoltaic.
RF	Renewable energy fraction.
RES	Renewable energy sources.
SR	Solar radiation.
STC	Standard test conditions.
STP	Standard temperature and pressure.
TL	Thermal loads.
TV	Television.
TLC	Thermal load controller.
TEL	Total electrical loads.
TES	Thermal energy storage system.
USA	United States of America.
WT	Wind turbine.
yr	Year.

Symbols

E_{ls}	Electrical energy served by the microgrid system (kWh).
α_P	Temperature co-efficient of power.
η_{con}	The efficiency of the converter.
ρ	Actual air density.
ρ_o	Air density at STP.
$	Dollar.
$/kW	Dollar/kilo Watt.
$/L	Dollar/Liter.
%	Percentage.
^0C	Degree centigrade.
a & b	Coefficients.
$CRF_{i,n}$	Capital recovery factor with i expressed as a percentage of the interest rate.
$C_{power,l}$	The grid power price for rate l ($/kWh).
$C_{sellback,l}$	The callback rate for rate l ($/kWh).
d	day.
D_{NPC}	Total net present cost ($).
$Dann_{total}$	Total annualized cost ($/yr).
$E_{gridpurchases,l,m}$	The energy purchased amount from the grid in month m during the time that rate l applies (kWh).
$E_{gridsales,l,m}$	The amount of energy sold to the grid in month m during the time that rate l applies (kWh).
E_{grid}	The amount of power sold to the grid by the microgrid system (W).
$E_{non-ren}$	Non-renewable electrical production (kWh).
$E_{reserved}$	Total electrical load served (W).
F_{cons}	Fuel consumption ($/L).
f_{PV}	The derating factor of PV.
f_{ren}	Renewable energy fraction.
G_T	Solar radiation incident on (kWh/m^2/d).
$G_{T,STC}$	Incident radiation at STC (kWh/m^2/d).
h	Loading process period (duration).
$H_{non-ren}$	Non-renewable thermal production.
H_{served}	Total thermal load served (kW).
hrs	Hours.
i	Annual interest rate (%).
kg	kilogram.
kW	kilo Watt.
kWh	kilo Watt hour.
L	Litre.
L_{Proj}	Project lifespan (yrs).
L_{served}	Total electrical load served (kW).
ln	Natural logarithm.
M	Million.
m	Meter.
m/s	Meter per second.
m^2	Meter square.
mAh	Milli ampere-hour.
MW	MegaWatt.
MWh	Megawatt hour.
n	No. of years.
N_{batte}	No. of batteries in a storage bank.
P_r	Rated power of the windmill (kW).
$P_{DG,r}$	Rated power at the DG (W).
P_{DG}	Power production by DG (kW).
P_{in}	Input power (kW).
P_{out}	Output power (kW).
P_{rene}	Total renewable power output (kW).
$P_{WTG,STP}$	WT output at STP (kW).
P_{WTG}	WT output power (kW).
P_{wt}	WT output power (kW).
$Q_{lifetime}$	Lifetime storage throughput (kWh).

Q_{thrpt}	Annual storage throughput (kWh).
$R_{batte,f}$	Storage float life (yrs).
R_{batte}	Storage back life (yrs).
t	Time.
TC	PV cell temperature (°C).
TC_{STC}	The temperature of PV cell at STC.
TEL	Total electrical load.
U_{anem}	Speed of the wind at the anemometer height (m/s).
U_{hub}	Speed of the wind at HH (m/s).
V	Volts.
v	wind speed (m/s).
V_r	Rated wind speed of the windmill (m/s).
V_{cut-in}	Cut-in wind speed of a windmill (m/s).
$V_{cut-out}$	Cut-out wind speed of a windmill (m/s).
WT	Wind turbine.
Y_{PV}	The relevant capacity of PV (kW).
yr	Year.
Z_o	Surface roughness length (m).
Z_{anem}	Anemometer height (m).
Z_{hub}	HH of the turbine (m).

I. INTRODUCTION

A. BACKGROUND

The conventional sources such as fossil fuel resources are declining day by day due to the increase in demand of electric power, due to this more power will be consumed by the consumers. In this context there is a need to produce the power from other sources such as from renewable energy sources. The renewable energy sources consists of advantages than conventional sources, such as pollution free, free of cost etc. But due to the intermittent nature of the renewable energy sources they are providing less power. To increase the output power from them there is a need to use hybrid renewable energy sources [1].

Remote areas development, especially in developing nations like India, primarily depends on electrical power. They are located far away from the utility grid. So the electrical power distribution to remote locations is difficult for economic growth, better living conditions, job creation, and poverty eradication. So, most of the consumers in remote places experience difficulty with poor power quality, power outages and regular power fluctuations. Extension of the utility grid to remote areas is economically unfeasible and inaccessible due to reduced economic potential [2]. As a result, power shortages in these areas might be resolved by implementing a GIHMGS that includes renewable energy sources (RES). Solar photovoltaic (PV), wind turbine (WT), and diesel generator(DG) have traditionally been used to satisfy load demand needs with optimal, feasible, and reliable electricity. This GIHMGS may provide inexpensive and continuous electricity to consumers living in rural areas. Furthermore, GIHMGS developed in rural areas may boost power usage and economic development while overcoming problems associated with limited fossil fuel sources [3].

Depending on how they operate, there are two types of hybrid renewable energy systems (HRES): stand-alone and grid-connected systems. The stand-alone approach is the most efficient approach for remote areas to provide continuous electrical power at the lowest levelized cost of energy [4]. These off-grid and grid-integrated microgrids are simulated using different tools to analyse their performance before implementation in any location. Even though other softwares are available in the literature, HOMER is used in this research since it decreases design complexity and conducts a techno-economic analysis of GIHMGS. So, a few papers were reviewed in this field of study that has previously been completed utilizing HOMER to identify research gaps and fix them with current improvements [5]. Figure 1 depicts the overall diagram of the research. Figure 2 shows GIHMGS with different components such as solar PV, wind turbine, diesel generator, converter (CON), grid, battery storage system and electrical load. All these components are connected to AC/DC buses according to their properties. This overall configuration is used to provide sustainable power to rural areas with lowest Levelized cost of energy(LCOE) [6]. Table 1 describes the publications of similar research on this field of research work in the last few years on construction of the optimal GIHMGS system using HOMER for rural electrification according to the availability of RES and its potentials, such as annual solar radiation (ASR), and annual wind speed (AWS). Generally, the optimal system will design according to the considered location, load, potentials, and sources. From Table 1 it can be concluded that if the LCOE decreases, it indicates to minimum net present cost (NPC), highest renewable energy fraction (RF) and leads to uninterrupted power supply for the considered location. So, all the researchers are interested in reducing the LCOE of the hybrid renewable energy system (HRES). In [10] the authors designed an optimal system i.e. PV/Grid in the location Baghdad, Iraq. In this research, they analyzed a solar PV system's techno-economic and environmental viability that can provide the load during grid availability and outages. In this location the available solar radiation is 4.5 $kWh/m^2/d$, total load-6300 kW and the carbon emission produced is 4533 kg/yr.

In [12], the authors designed an optimal system PV/battery storage system(BS)/DG/Grid at Diyala, Muqdadiyah district, Iraq. The optimal HRES based on available RES, and techno-economic analysis is performed. In [13], the authors developed an PV/fuelcell(FC)/Grid at University campus in India. To design an optimal system, it is essential to consider the LCOE purchased, sold to the conventional grid and managed between system components and the traditional grid seamlessly. In [14], the authors constructed an PV/WT/DG/Grid at Malayer University campus, Malayer, Iran. To design an optimal system based on the availability of RES and techno-economic feasibility analysis. It was a

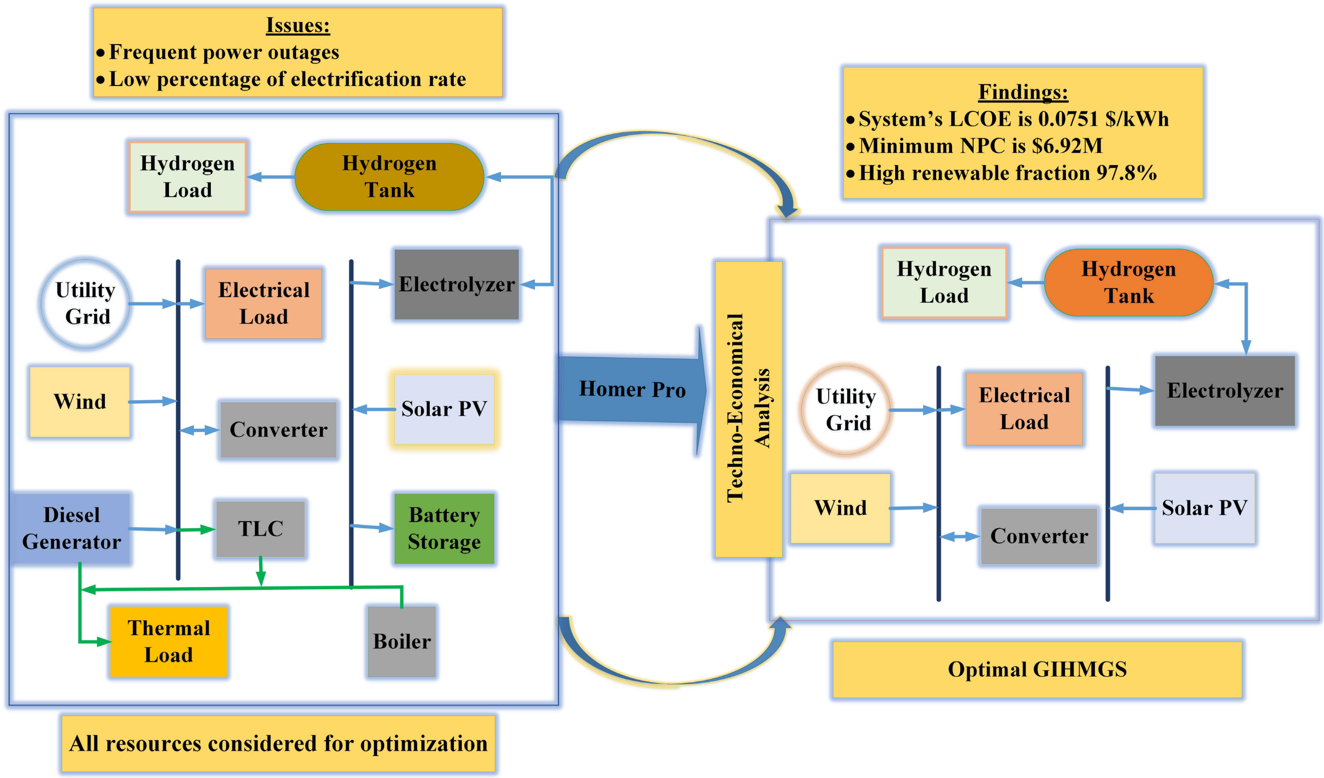

FIGURE 1. The overall circuit diagram of the GIHMGS.

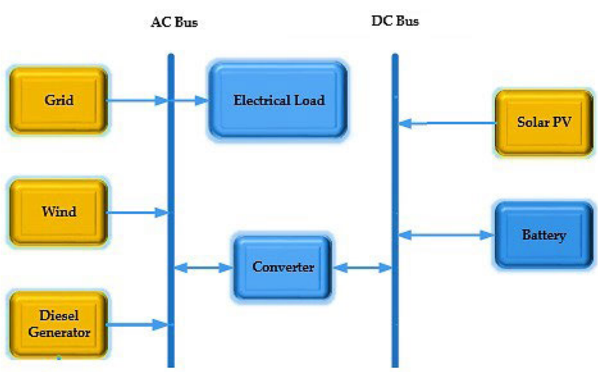

FIGURE 2. Circuit diagram of on-grid hybrid AC/DC microgrid.

cost-effective system. In [18] the authors proposed an optimal system PV/WT/BS/Grid at the considered location Chintalayapalle village, Tadipatri, Andhra Pradesh. Here, they designed the optimal system depending on available RES and by performing techno-economic and sensitivity analysis. In [19], the authors designed an optimal grid-connected PV-based power plant. To develop an optimal and reliable energy system, the area of the installed solar PV system and the part of the electricity bought from the utility grid must both be maximized. With or without considering the storage system, the optimization issue was addressed. The objective of the optimization problem is to reduce the system's NPC under the reliability constraint, which was determined by the loss of power supply probability (LPSP). An optimization model is created for the household energy system based on solar PV, fuel cells, and batteries [20]. This model may choose the best operating strategies while ensuring dependable system two heuristic methods and three more well-known meta heuristic optimization techniques: the genetic algorithm (GA), the imperialist competition algorithm and the original particle swarm optimization (PSO). Based on the results, it is clear that the hybrid solar PV-hydrogen system is the more reliable and dependable option for meeting the energy needs of homes shortly and that the suggested PSO algorithm with shrinkage factor (PSOCF) and adaptive inertia weight PSO (PSOAIW) algorithms perform better than competing algorithms [21].

In [22], the authors provide a global performance comparison of HRES, grid-connected solar PV systems, and stand-alone solar PV systems. A self-contained solar PV system is ideal for powering a single dwelling or a remote outpost. A hybrid energy system may combine several sources to generate electricity for rural electrification in off-grid areas. With grid-connected PV systems, any extra electricity can be fed into the grid, creating additional revenue. In this study, the research efforts of scientists worldwide into renewable energy sources are highlighted, emphasizing their application to the electrification of rural areas. In addition, the research conducted on using renewable energy for plug-in electric vehicles (PEV) worldwide was covered.

TABLE 1. Location-Based other GIHMGS design details.

Author/Year/ Reference	Optimal GIHMGS model	Selected Location	Available Potentials & Load	Objectives	Highlights
Li He, et al., /2018 [7]	WT/BS/Grid	Beijing, China	ASR: 4.12 kWh/m$^2/d$, AWS: 4.53 m/s, Domestic Load (DL): 29MWh/d	LCOE, NPC	To develop an optimal On-grid hybrid AC/DC system using techno-economic feasibility analysis.
Mehdi Jahangiri, et.al.,/2019 [8]	PV/WT/Grid	Bandar Abbas city in the South of Iron	ASR: 5.403kWh/m$^2/d$. AWS: 4.013 m/s. Total Electrical Load (TEL): 1000MWh/d	LCOE, NPC, Hydrogen	To design on and off-grid hybrid AC/DC microgrid systems using techno-economic analysis on providing electrical power and hydrogen with RES.
Kanzumba Kusakana / 2019 [9]	PV/Grid	Bloemfontein, South Africa.	TEL: 8000W	LCOE, NPC	To determine the available resources cost saving, obtainable using the optimal system.
Shakti Singh, et.al.,/2020 [11]	PV/fuel cell (FC) /Grid/HTank	University campus in India.	ASR: 0.80 kWh/m$^2/d$, AWS: 1m/s, TEL: 135 MWh/yr	LCOE	To design an optimal system, it is essential to consider the LCOE purchased, sold to the conventional grid and managed between system components and the traditional grid seamlessly.
Barun K. Das /2021 [17]	PV/DG/BS/Grid	Rajshahi, Bangladesh	ASR: 4.88 kWh/m$^2/d$, AWS: 2.64 m/s, CI: 0.54, TEL: 2,28,991 kWh	LCOE, NPC, CO2, RF	A thorough technical economic analysis of optimal systems is investigated and the advantages of HESs for the environment are explored.
Alibakhsh Kasaeian, et al., /2021 [15]	PV/DG/Biogas /Grid	Golshan, Iran	ASR: 4.80 kWh/m$^2/d$, AWS: 3m/s TEL: 430 kWh/day	LCOE, NPC, RF	Perform a techno-economic and sensitivity analysis for different diesel prices, and design the best system based on RER.
J. Jeslin Drusila Nesamalar/2022 [16]	PV/DG/Grid	Virudhunagar, Madurai, Tamil Nadu, India.	ASR:5.34 kWh/m$^2/d$, TEL: 1023.2 kWh.	LCOE, NPC	To develop an optimal system through technical and economic study.

In [23], the authors explored the potential for power production through hybrid WT, solar PV, and biomass systems. They focused on the techno-economic feasibility analysis of a GIHMGS for the residents of Kallar Kahar in the Punjab region of Pakistan. The technical and economic research shows that the HRES can produce above 50 MW. Residential and business energy costs are evaluated in light of peak load patterns. In [24], the authors developed a model based on the framework of mixed-integer evaluation of an energy management system linear programming (MILP) to explore the co-operative operation in a building, (1) the energy trading capability in both directions of an electrical vehicle (EV) fleet arriving at an office building under a stochastic EVs' driving schedule, (2) the impact of solar PV uncertainty on energy management system (EMS) operation based on accurate smart-metering data and comparing it with a deterministic solar PV production approach, and (3) all case studies' total estimated daily cost for the system was shown to be substantially lower compared to their similar deterministic scenarios, proving the need for the stochastic method.

In [25], the authors proposed a study that suggests hydrogen has economic advantages over batteries for long-term energy storage in an off-grid hybrid energy system in Golden, Colorado, USA. The simulation results show that the Levelized cost of energy, NPC and LCOH are \$0.78/kWh/d, \$11M, and \$20.7/kg, respectively.

B. OBJECTIVE FUNCTION AND ECONOMIC EQUATIONS

The primary goal is to minimise the LCOE, carbon emissions, and raise the renewable energy fraction of the optimal system for the investigated location, which may assist more rural people for continuously using electrical power. Since the best design includes and a hydrogen tank and an electrolyser for hydrogen-powered applications. The suggested approach applies to offline and online GIHMGS with non-linear systems [26]. The anticipated technique yields a complete result, including optimal design. The presented method selects the most feasible GIHMGS design by addressing the system's objectives and difficulties. As a consequence, the proposed approach meets the end customers' need for financial advantages in an efficient way.

The following equations are used to determine the factors which are used while designing the system. The overall system cost includes the cost of all optimal system components. The system's total annualized cost determines NPC and LCOE. This proposed system is heavily influenced by "the NPC and LCOE." The NPC approach benefits various HRES configurations developed during the optimization process [27].

Levelized COE: The HRES's LCOE is the cost per unit of energy generated. In another way, it is the ratio of the system's annual fee to the total number of energy units produced by the HRES and determined by Equation (1) [2]:

$$LCOE = \left[\frac{\text{Total annualized cost (\$)}}{\text{Total energy generated } (kWh)} \right] \quad (1)$$

Capital Recovery Factor(CRF): It is calculated by the Equation (3) [2]

$$CRF(i, n) = \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] \quad (2)$$

where "n-indicates the number of years, and i-denotes the annual rate of interest (%), a drop in rate of interest may decrease CRF, leading to a rise in NPC".

Net Present Cost(NPC): It is represented by using "the total annualized cost and the LCOE of the system". The following Equation (2) [2] gives NPC as:

$$D_{NPC} = \frac{D_{\text{total,ann}}}{\text{CRF}\left(i, L_{\text{proj}}\right)} \quad (3)$$

where "$D_{total,ann}$-total annualized cost (\$/yr), i-annual rate of interest (%) (discount rate), L_{Proj}-the life span of the project (yrs), and $CRF_{i,n}$-capital recovery factor with i expressed as a % of the interest rate".

Renewable Fraction(RF) f_{ren}: It is "the fraction of the power produced from renewable sources and transferred to the system". It is having no-dimensions and is indicated as f_{ren} and calculated by Equation (4) [2]:

$$f_{\text{ren}} = 1 - \frac{E_{\text{non-ren}} + H_{\text{non-ren}}}{E_{\text{served}} + H_{\text{served}}} \quad (4)$$

where "$E_{non-ren}$-the non-renewable electrical production (kWh/yr), $H_{non-ren}$-the non-renewable thermal production (kWh/yr), E_{served}-the total electrical load served (kWh/yr), H_served-the full thermal load served (kWh/yr)".

C. HOMER SOFTWARE

Based on the available load profile, it is used to build the most efficient HRES at the considered location. The following Figure 3 shows the procedure of Homer software.

The first step in this investigation includes collecting data on solar and wind potential and assessing the area's load profile. Several components are used in the system's design. First, the sizes of both elements and economic criteria are considered. Finally, optimization is performed to assess the cost-effectiveness of the GIHMGS model [27], [28].

1) ADVANTAGES

- This software is the world standard for improving the designs of off-grid and grid-integrated power systems so that reliable electricity can be provided in remote areas [29].
- However, many technical alternatives, cost variances, and the availability of energy sources complicate these choices. Therefore, HOMER's optimization makes analyzing various configurations of the HRES easier.

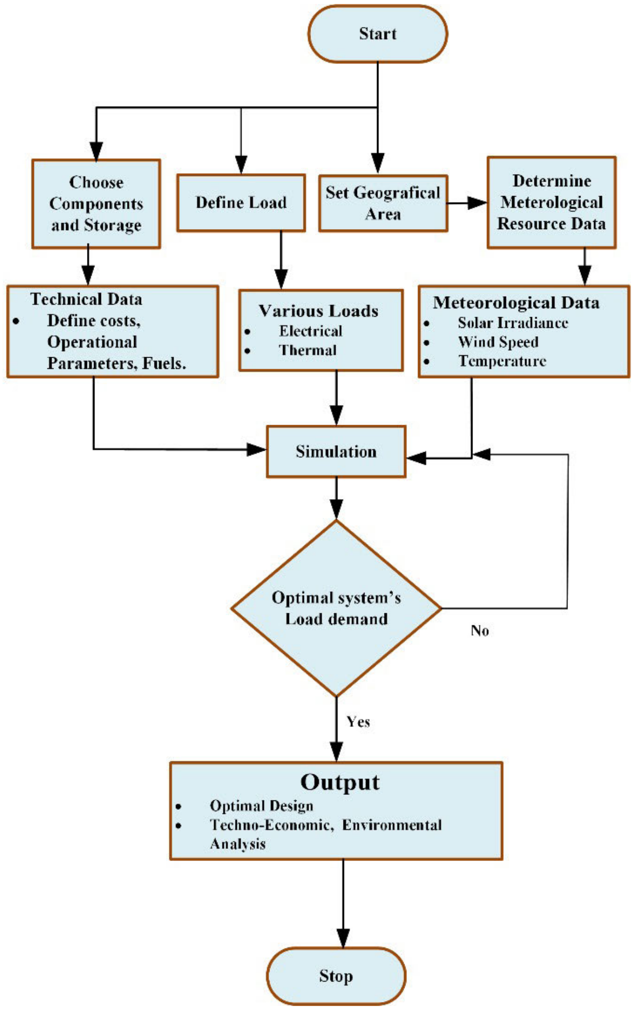

FIGURE 3. Homer software procedure.

- HOMER also shows the results of simulations in different graphs and tables, which makes it easier to compare setups and figure out how techno-economically beneficial they are. Export tables and charts for use in presentations and reports.

The rest of the paper is organized as follows: Section II provides a complete summary of the methodology, assumptions, components, and site load information, as well as an explanation of the site's RES availability. Section III explains optimization outcomes, a technical and economic analysis, component's description, an economic assessment, and a proposed optimal system design. Finally, Section IV outlines the research's conclusion.

II. METHODOLOGY, ASSUMPTIONS, AND COMPONENTS

To develop a GIHMGS, a unified structure would be constructed based on the RES available in the selected area,such as environmental constraints and financial risk. Substantial GIHMGS design inputs must comprise a daily load profile for seasonal fluctuations, onsite meteorological data, the precise location where an optimum GIHMGS should be constructed and presented production capacity. HOMER software may recognise the optimal GIHMGS architecture among the different designs [30]. The LCOE, NPC, and operational and maintenance costs (O&M) are considered using this designing process. After developing the optimal GIHMGS, the HOMER software does the techno-economic analysis. This study recommends future savings and statistics on the selected site's system planning, policy decisions and extension.

A. SITE DETAILS

The considered site in the study is Doddipalli village, Chittoor district, A.P., India, with latitude and longitude of 13° 02' 04.83'' N, 79° 12' 59.67'' E, and 305 m above from the sea level. According to census statistics, 5292 individuals reside in 1309 houses, with 2–5 persons in each home. The rate of literacy is roughly 68.2%. Cultivation is the leading business in this area, which contains 60-80 hectares of agricultural land surrounded by granite mining zones [31]. The utility grid energy is available and insufficient to fulfil increasing load demand, mainly during the summer. Consequently, to achieve the increased need for continuous energy delivery, a GIHMGS is necessary at this location.

B. LOAD PROFILE OF THE CONSIDERED AREA

An onsite field study was conducted to collect data on energy consumption of various loads, such as domestic load (DL: lights, television, radio, fans and refrigerators), community load (CL: rice and oil mills, micro-business shops, and grilled stone machines), and agricultural load (AL: water pumping motors), over 24 hours to determine the load demand. The surveyed load data was sent as input to the HOMER software. The HOMER will use the hourly load profile and random irregularity variables to look at 8,760 hours of total hourly load data over a year (i.e., day-to-day variance). They were treated at 10% and 20% in this investigation, with 60 minutes of time step size. Table 2 highlights the overall load data obtained in that region, with higher morning and evening load demands. As a result, the load demand and loading procedure time(h) will be included for assessing energy usage. Equation (5) [6] is used to calculate the total energy demand (kWh).

$$TotalEnergyDemand(kWh) = \sum_{i=1}^{n} *(Loaddemand(kW) \times Duration(h)). \quad (5)$$

The average load profile is according to the daily load profile of the considered site. Figure 4 shows a seasonal load profile of DL for a household part in the community over a year. This scenario of load consumption involves 1309 residences in the considered location with average load demand. DL refers to all electricity used in the region for domestic purposes. Based on HOMER software, the peak load of 77.67 kWh and daily demand of 536.32 kWh/d of DL was obtained. Figures 5 and 6 shows the seasonal load profiles for CL and AL respectively.The peak load and daily load of the CL are 18.6 kW, 126.91 kWh/d respectively.The peak load and daily load of the AL are 11.25 kW, 41.88 kWh/d respectively. Moreover, the random variability function of HOMER software may generate these load profiles. Furthermore, Figure 7 gives the graphical representation of total electric load's (TEL) daily load profile for 24 hours at the selected area.

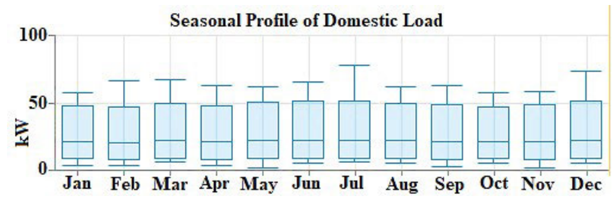

FIGURE 4. Seasonal profile of DL.

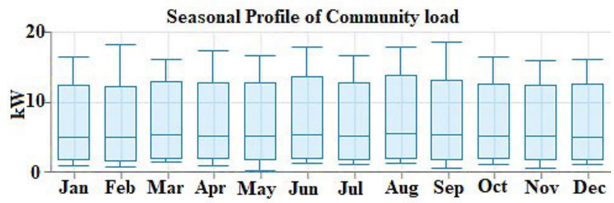

FIGURE 5. Seasonal profile of CL.

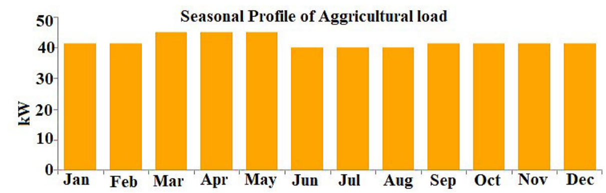

FIGURE 6. Seasonal profile of AL.

Table 2 shows the hourly load consumption of the total electrical load (DL, CL, and AL) per day in the considered area. From Table 2 it is observed that maximum power was consumed by DLs and CLs from 8am to 11am, but ALs consume maximum power at some particular time when three phase power is available i.e. 10am, 12 pm and 5pm. Table 3 shows the different electrical power consuming components in different load conditions.

C. THERMAL LOADS

According to the demand for thermal energy, the TL's applications were, room heating, industrial process heating, and water heating. A waste heat recovery generator (boiler) is used to meet the additional energy demand for this load. The percentage of these loads is 5% in all electrical loads and data was gathered for 24 hours. The annual average for this load is 126.9 kWh/d, with a peak load of 18.6 kW and the load factor of 0.28. Consequently, the main purpose of integrating this TL in the GIHMGS is to describe the effect of excess energy provided by the TL into the system [32].

TABLE 2. Total load (DL, CL & AL) details.

Hours	DL (kWh/day)	CL (kWh/day)	AL (kWh/day)
1	5.036	1.397	0
2	5.755	1.397	0
3	7.194	2.096	0
4	8.633	2.096	0
5	10.791	2.096	0
6	14.388	3.493	0
7	14.388	4.192	0
8	18.705	5.589	0
9	21.583	5.589	0
10	17.985	6.987	0.625
11	18.705	6.987	0
12	10.072	2.794	0.625
13	7.194	2.096	0
14	12.949	4.192	0
15	14.388	4.192	0
16	12.949	3.493	0
17	10.072	2.794	0.625
18	8.633	2.096	0
19	7.913	2.096	0
20	7.194	2.096	0
21	6.474	2.096	0
22	5.755	1.397	0
23	5.036	1.397	0
24	5.036	1.397	0
Total Load (kWh/day)	536.32	126.9	41.67
	704.89		

TABLE 3. Load information with different electrical equipments.

Load categories	Loads (appliances)	Load (kWh/d)
Domestic Loads	CFL bulbs, Tube light (fluorescent), light emitting diode (LED) bulbs, TV, Exhaust fans, Radios, Ceiling fans Refrigerator, Electric iron boxes, Air coolers, Mixer grinders, Motor pumps, Phone chargers, Computer desktops, Air conditioners, Electric rice cooker, Water heater.	536.32
Commercial Loads	Health clinic centres, Schools, Worship places, Street lights, mini business centres, Commercial loads, Computer printers, Rice mills and welding shop	126.9
Agricultural Loads	Pumping motor, Irrigation Purpose.	41.67
Total Electrical Load		704.89

D. HYDROGEN LOADS

An external demand for hydrogen is called a ''hydrogen load''. Hydrogen will be generated using an electrolyser to store the surplus electrical energy. While small-scale electrolyser make sense in conjunction with renewable energy power plants, this work assumes the concentrated installation of electrolyser in a specific area [33].

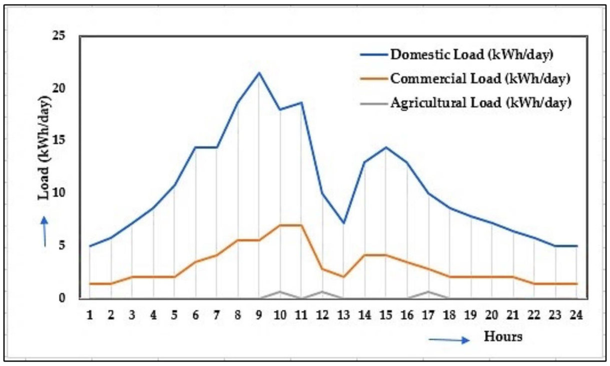

FIGURE 7. Graphical representation of the total load profile of the considered location.

The options for choosing the hydrogen load as the primary electrical and thermal loads are as follows: either synthesise hourly load data by inputting daily load profiles or import time series data. The electrolyser has a capacity of 5% of renewable power. The electrolyser's load factor exceeds 60% when linked to solar PV. To create 1 kg of hydrogen, a thoroughly efficient electrolysis plant would need 39 kWh of power. Unfortunately, the gadgets that are used for this purpose are less efficient. The typical operating number is around 48 kWh per kilogram of hydrogen [34].

E. RESOURCES ASSESSMENT

This research includes solar PV and wind energy as RES. As a consequence, wind speed and solar radiation were measured on a monthly and annual basis. Several modelling aspects, including technical, economic, and social effects, influence the optimal scaling of an GIHMGS [35].

F. SOLAR PV SYSTEM

This research focuses on RES like solar PV and wind energy for designing the GIHMGS. The SR is available at the considered site 10-12 hrs/d during the summer but only 6–8 hrs/d during winter. Additionally, summer temperatures in the region under consideration exceed 48°C. The solar irradiation and wind speed data provided by the NREL and NASA [36]. Figure 8 depicts the selected region's CI values (''Atmospheric clearness index and its range between 0 and 1'') and monthly average solar irradiance data. The value of CI ranges from 0.633 in February to 0.436 in July, with a mean of 0.5266.

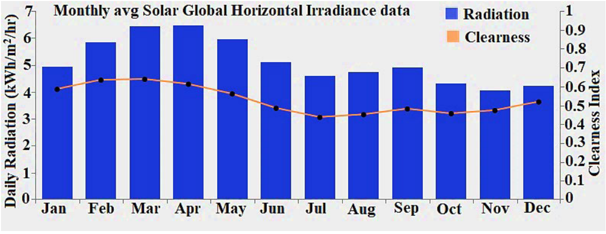

FIGURE 8. Monthly average solar radiation and CI details.

G. WIND ENERGY

Based on the NASA database, the average monthly wind speed at 50 m above the earth's surface has been 5.10 m/s over the past three decades. Figure 9 depicts the average monthly wind speed at the selected location. At this point, the surface roughness is 0.01 [37].

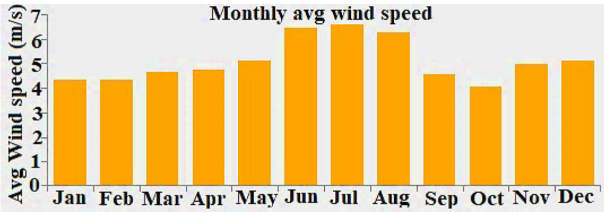

FIGURE 9. Details of monthly average wind speed.

H. TEMPERATURE

NASA's global energy resource database says that the monthly average atmospheric temperature at the selected location will be 26.37 °C for the next thee decades [38].

I. DESCRIPTION OF THE COMPONENTS

The primary components of the GIHMGS system are Solar PV, WT, BS, CON, DG, and load demand. The fundamental advantage of building a GIHMGS by integrating many RESs is that it improves operating characteristics, dependability, and overall potential. The GIHMGS architecture is based on the available load demand, technical specifications of the components, component costs, and wind speed and solar PV availability in the selected area. The HOMER software looks at how a system works by calculating the energy balance over time. It also computes the energy outflows of the GIHMGS components. It regulates the scheduling of different RES in the HRES during system operation. The HOMER program schedules the charging and draining of a battery [39]. Various RES may be mixed to create a wide range of combinations. The HOMER software also figure out the best design to meet the load requirements for the given location while staying within the given parameters. The GIHMGS also included a techno-economic analysis that looked at each component's capital cost, O&M cost, replacement cost, fuel cost, NPC, LCOE, and RF. The economic evaluation of this research makes the following assumptions: a 25-year project duration, a 10% interest rate, and a 3% inflation rate.

J. DETAILS OF TECHNO-ECONOMICAL ANALYSIS

The specifications of all components of GIHMGS are represented in Table 4.

1) SOLAR PV SYSTEM

Solar energy is one of India's many renewable energy sources for generating electricity in rural places where the power of the utility grid is restricted [40]. The solar PV module produces the power, which is proportional to the solar radiation (SR) quantity of the considered site. The yearly SR is expected to installation and capital costs for this solar PV module are \$3000/kW and \$10 per module, respectively. The performance of solar PV panels at each hour can be calculated using Equation (7) [2] based on the observed SR and atmospheric temperature.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}}\right)\left[1 + \alpha_P \left(T_C - T_{C,STC}\right]\right. \quad (6)$$

where Y_{PV}-the solar PV's relative capacity in kW, f_{PV}-the derating factor of solar PV in %, G_T-SR on solar PV in the present period in $kWh/m^2/d$, $G_{T,STC-SR}$ at STC kW/m^2, α_P-Power's temperature coefficient-0.5, $\%/^0C$, T_C-Temperature of solar PV cell in a given period $\%/^0C$ and $T_{C,STC}$-The solar PV cell's temperature at STC of 25^0C gives the energy response at STC ('STC is the emission of one kW/m^2, 25^0C solar PV cell temperature').

Depending on labour costs and shipping charges from the manufacturing site, the O&M cost of a solar PV array may be about \$10/kW/yr. The major disadvantage of the solar PV system is that it has no salvage value and a replacement cost equivalent to the installation cost. The system efficiency increases when the solar panel derating factor is adjusted to 0.96 (usually between 0.7 and 0.98) and the ground reflectance is set at 30%.

2) WIND ENERGY

In this study, the wind turbine has a cut-in speed of 4-5 m/s and also has a maximum power efficiency. This model's capital and O&M costs are \$1,028,115.00 and \$77,314.25, respectively [41]. A WT system evaluates the power it produces at each time step. Equation (7) [6] is used to calculate the wind speed of the turbine.

$$U_{hub} = U_{anem} * \frac{l_n\left(\frac{Z_{hub}}{Z_0}\right)}{l_n\left(\frac{Z_{anem}}{Z_0}\right)} \quad (7)$$

where U_{hub}-Wind speed at the hub height (HH) m/s; U_{anem}-Wind speed at the height of anemometer (m/s); Z_{hub}-Turbine's HH m; Z_{anem}-Height of the anemometer m; Z_0-Roughness length of the surface m; l_n-Natural logarithm. The output power gained by WT at standard conditions is determined using Equation (8) [6]

$$P_{WTG} = \left(\frac{\rho}{\rho_0}\right) * P_{WTG,STP} \quad (8)$$

where P_{WTG}-Output power of WT kW; $P_{WTG,STP}$-The output of WT at standard pressure and temperature kW; ρ-Real air density kg/m^3; ρ_o: Air density at general pressure and temperature 1.225 kg/m^3. So, the power produced by WT was determined by using Equation (9) [2].

$$P_{wt} = \left[V^3\left(\frac{P_r}{V_r^3 - V_{cutin}^3}\right) - \left(\frac{V_{cutin}^3}{V_r^3 - V_{cutin}^3}\right) * P_r\right] \quad (9)$$

TABLE 4. Technical specifications of the all components of the GIHMGS.

Solar PV		Wind (Enercon-E53)	
Rated Capacity = 727 kW	Minimum Output = 0kW	Total Rated Capacity = 800kW	Maximum output = 791kW
Mean Output = 125kW	Maximum Output = 500kW	Mean Output = 221kW	Wind penetration = 800%
Mean Output/Day = 3,010 kWh/d	PV Penetration = 454%	Capacity Factor = 27.6%	Hours of Operation = 8,595hrs/yr
Capacity Factor = 17.2%	Hours of Operation = 4,380 hrs/yr	Total Production = 19,36,798 kWh/yr	Levelized cost = 0.0845 $/kWh
Total Production = 10,98,700 kWh/yr	Levelized Cost = 0.174 $/kWh	Boiler	
Dedicated Converter = 500kW		Hours of operation = 5,933 hr/yr	Fuel consumption = 11,715L/yr
Converter		Total production = 93,711 kWh/yr	Specific fuel consumption = 0.125 L/kWh
Inverter	Rectifier	Mean & min. output = 10.7kW, 0.256kW	Fuel energy input = 1,10,248 kWh/yr
Capacity = 397kW	397kW	Max. output = 58.4kW	Mean efficiency = 85%
Mean output = 60.7kW	11.9kW	Generic electrolyser	
Maximum output = 397kW	100kW	Rated capacity = 100kW	Hours of operation = 7,472 hr/yr
Capacity Factor = 15.3%	3.01%	Mean input = 29.1kW	Mean output = 0.627kg/hr
Hours of operation = 2,918 hrs/yr	3,551 hrs/yr	Max. input = 100kW	Max. output = 2.15kg/hr
Energy out = 5,31,717 kWh/yr	1,04,663 kWh/yr	Total input energy = 2,54,744 kWh/yr	Total production = 5,490kg/yr
Energy in = 5,59,702 kWh/yr	1,10,172kWh/yr	Capacity factor = 29.1%	Specific consumption = 46.4 kWh/kg
Losses = 27,985kWh/yr	5,509kWh/yr	TLC	Hydrogen Tank
Hydrogen		Operating hours = 3,007 hrs/yr	Hydogen Storage Capacity = 20kg
Hydrogen Load = 5470 kg/yr	Levelized COH = 92.6	Mean output = 85.3kW	Energy Storage Capacity = 667 kWh
		Max. output = 1,241kW	Tank Autonomy = 22.7hr

If $V > V_{cutin}$ or $V < V_r$, Where P_r-Rated power of WT, V-Wind speed m/s, V_{cutin} and V_{cutout}: Cut-in and a Cut-out speed of the wind, V_r-Rated speed of WT.

3) DIESEL GENERATOR

When the power generation by the RES is decreased, a DG is used as a backup source to produce power and continuously provide it to consumers during peak demand situations. The HOMER software is used to choose the auto-sized Kohler DG for the GIHMGS design, which automatically adjusts itself to fit load requirements under all conditions [42]. If the entire amount of electricity produced by non-conventional energy sources and storage cells was insufficient to fulfil load requirements, then DG was used as a unified power system. Equation (11) [2] indicates the power output determined by the diesel generator's gas volume in each time.

$$F_{cons} = a.P_{DG} + b.P_{DG,r} \tag{10}$$

where P_{DG}-Power generated by DG (kW) on an hourly basis (t), F_{cons}-Fuel consumption (L/hr), $P_{DG,r}$-Rated power of the DG generated on hourly basis (t), a and b are coefficients (L/kW).

4) BATTERY

A battery storage device is built into the GIHMGS system as a backup to ensure it works reliably and continuously if the electricity goes out [43]. Equation (11) [2] calculates the battery's storage bank life.

$$R_{batte} = \begin{cases} \left(\frac{N_{batte} * Q_{lifetime}}{Q_{thrpt}}\right); iflimited \\ bythroughput \\ R_{batte,f}; iflimited \\ bytime \\ min\left(\frac{N_{batte} * Q_{lifetime}}{Q_{thrpt}} * R_{batte,f}\right); if \\ limitedbythroughputandtime \end{cases} \tag{11}$$

where $R_{batte,f}$-Float life of BS (yrs); R_{batte}-Life of BS (yr); N_{batte}-No. of batteries; $Q_{lifetime}$-Lifetime of BS throughput (kWh); Q_{thrpt}-Annual BS throughput (kWh/yr).

5) CONVERTER

A generic converter used to design a GIHMGS can convert the total power produced by RES [44]. A converter's size, capacity, and design all parameters affects to its cost value. Equation (13) [6] calculates lifespan (15 yr) for inverter and rectifier inputs with relative capabilities and efficiencies of

100% and 95%, respectively.

$$\eta_{con} = \frac{P_{out}}{P_{in}} \quad (12)$$

where: η_{con}-Converter efficiency;P_{out}-Output power of converter, and P_{in}-Input power of converter.

6) BOILER

A boiler is interconnected to the GIHMGS as a backup source of heat energy. It provides the necessary TL whenever it is necessary. The boiler becomes essential when a TL is linked to the GIHMGS system [29]. The themal load contrller (TLC) allows for huge power production and the integration of loads into the thermal bus. HOMER software was used to pick a baseline TLC of 1 kW. The cost details includes capital cost, replacement cost and O&M cost are \$200/kW, \$200/yr, and \$20/yr, respectively, for each converter with a lifespan of 20 yr. This research determines a 15-year lifespan for inverter and rectifier inputs with 100% and 95% relative capacities and efficiencies, respectively.

7) GRID

The cost of energy supplied from Electricity Distribution Company Limited (EDCL) was \$0.145/kWh. The GIHMGS' surplus electricity might be sold back to the utility grid at a feed-in tariff of \$0.08/kWh [39]. Equation (14) [3] is used to compute the total annual energy charge.

$$C_{grid,energy} = \sum_{n=l}^{rates} \sum_{n=m}^{12} E_{gridpurchases,l,m} * C_{power,l} - \sum_{n=l}^{rates} \sum_{n=m}^{12} E_{gridsales,l,m} * C_{saleback,l} \quad (13)$$

"where $E_{gridPurchases,l,m}$-The energy purchased amount from the grid in month m during the time that rate l applies (kWh), $C_{power,l}$-the grid power price for rate l (\$/kWh), $E_{gridsales,l,m}$-the amount of energy sold to the grid in month m during the time that rate l applies (kWh), $C_{sellback,l}$-the sell-back rate for rate l (\$/kWh)".

Emissions of air pollutants are produced mainly by components such as DG's, TL, boilers, and external utility grid [48].

8) SYSTEM ECONOMICS

The GIHMGS has a nominal discount rate of 8% to 10%, with an expected inflation rate of 2%. The annual capacity downfall of the proposed system is predicted to be between 0% and 10%. The project lifespan of the GIHMGS design is estimated to be between 15 and 25 years. The operational reserve is 10% of hourly load demand, 80% of solar PV production, and 70% of WT output. The RES components must be at least 40%.

9) OTHER CONSTRAINTS

In this study, the following restrictions were considered while doing the analysis: Maximum annual capacity storage-10%, minimum renewable fraction-40%, load in current time steps-10% along with annual peak load-5%, percentage solar power output-80% and wind power output-70%, grid real-time rates-800 kW, annual purchase capacity-2000 kW, grid capital cost-\$10,000 /km, distance-100 km, and grid rate definition is randomly generated into 8760 lines of two-column format based on power price and sell back price of the grid.

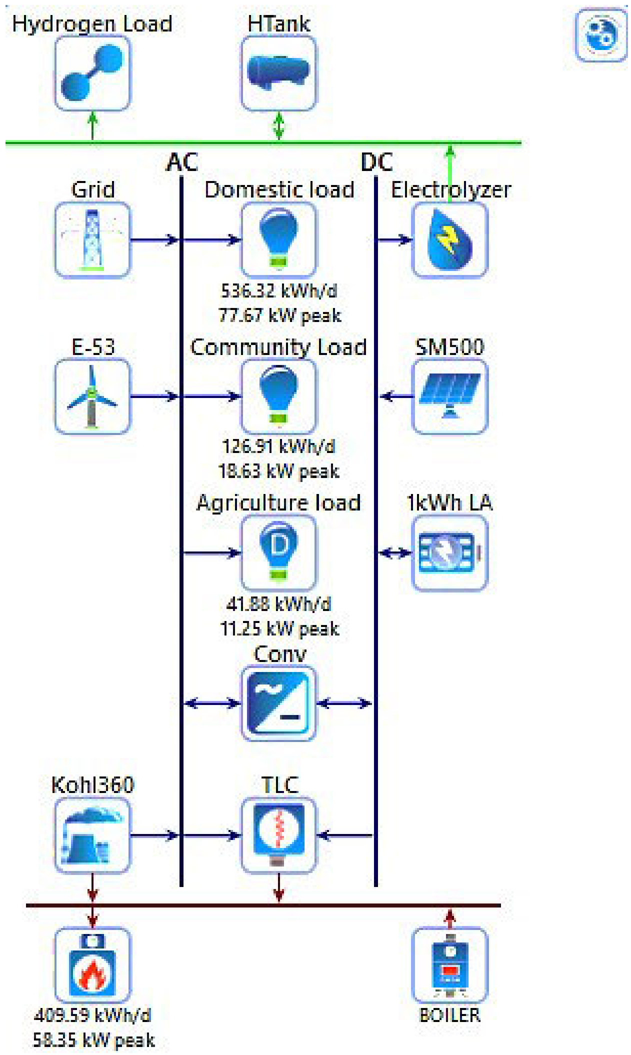

FIGURE 10. GIHMGS model using HOMER.

III. SIMULATION RESULTS AND DISCUSSIONS

The optimization and simulation objectives of this research are to create optimal GIHMGS design using HOMER software. From the optimization results, the economic parameters, such as LCOE, minimum NPC, and high RF, were utilized to rank and select the optimal GIHMGS model. As per the result, the technical and economic analysis of the GIHMGS is performed to determine the proposed system for a considered site. Figure 10 shows the GIHMGS design created using HOMER software. The Component input variables

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

SM500 (kW)	E-53	Kohl360 (kW)	1kWh LA	Grid (kW)	Electrolyzer (kW)	HTank (kg)	TLC (kW)	Conv (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
13.9	4			9,999	700	10.0	500	94.0	CC	$6.92M	$0.0751	$27,454	$6.59M	97.8
13.5	4		1	9,999	700	10.0	500	97.9	CC	$6.92M	$0.0752	$27,566	$6.59M	97.8
	4			9,999	700	20.0	500	66.2	CC	$6.92M	$0.0754	$30,449	$6.56M	97.8
	4		3	9,999	700	20.0	500	67.4	CC	$6.92M	$0.0754	$30,530	$6.56M	97.8
13.9	4	360		9,999	700	10.0	500	94.0	CC	$6.92M	$0.0752	$27,423	$6.60M	97.8
13.5	4	360	1	9,999	700	10.0	500	97.9	CC	$6.93M	$0.0752	$27,535	$6.60M	97.8
	4	360		9,999	700	20.0	500	66.2	CC	$6.93M	$0.0755	$30,418	$6.57M	97.8
	4	360	3	9,999	700	20.0	500	67.4	CC	$6.93M	$0.0755	$30,499	$6.57M	97.8
1,269				9,999	700	20.0	500	402	CC	$9.28M	$0.646	$248,359	$6.34M	85.3
1,269		360		9,999	700	20.0	500	402	CC	$9.29M	$0.647	$248,328	$6.34M	85.3
1,272			10	9,999	700	20.0	500	402	CC	$9.30M	$0.647	$248,496	$6.35M	85.3
1,272		360	10	9,999	700	20.0	500	402	CC	$9.31M	$0.647	$248,465	$6.36M	85.3

FIGURE 11. Optimization results using HOMER.

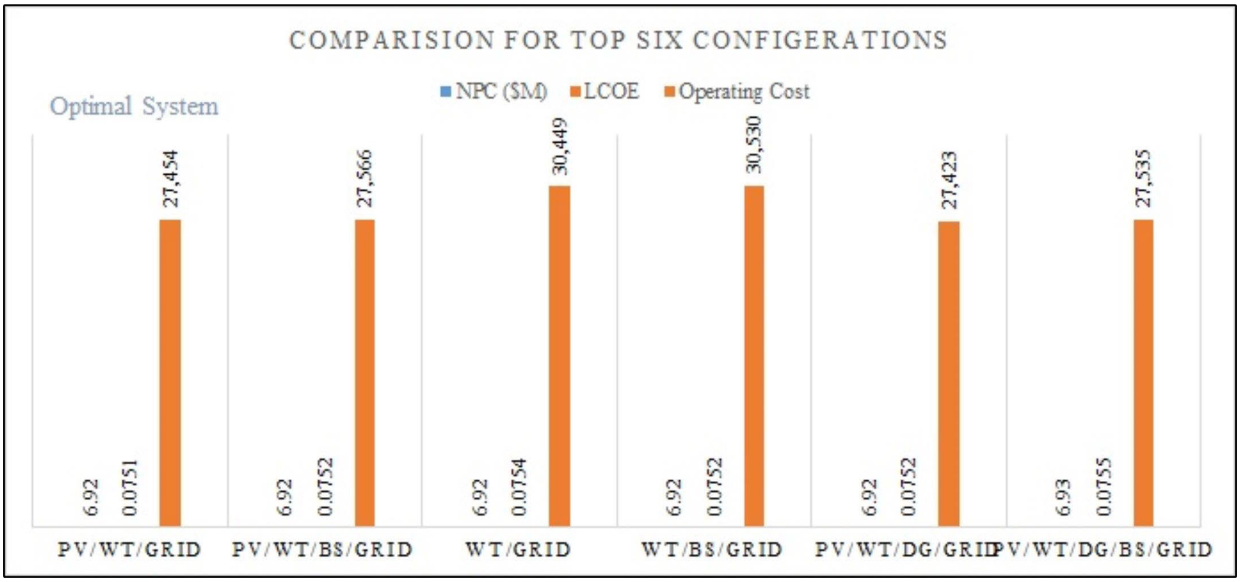

FIGURE 12. Comparision for top six configurations.

like available potential, cost, load demand, and other restrictions are determined and shown in the output results of the HOMER software.

Moreover, it produces large number of GIHMGS that are suitable and economical for meeting the load demand at the investigated site. The optimization results of the suggested optimal system are shown in Figure 11. The optimal system is the top most system in the Figure 11. Figure 12 shows the comparison of the simulation results, with the first six configurations. As a result, it is determined that the GIHMGS system comprised of PV/WT/Grid is the most economical system for the considered site and having a total NPC of \$6.92M and an operating cost of \$27,454/yr, which is less than the total NPC of all other configurations. Therefore, it has been noticed that the proposed system may be well suited for the chosen location with a hybrid system that includes solar PV-13.9 kW, WT-800 (4) kW, an electrolyzer of 700 kW, a large generic converter of 94 kW, a HTank-10 kg of capacity, and a TLC-500 kW. This design may be advised to enhance the community's well-being in the considered location.

A. ANALYSIS OF GIHMGS PERFORMANCE

The optimal configuration of the GIHMGS model was developed from the HOMER. The estimated lifespan of the

TABLE 5. Summary of generation, consumption, excess, and unmet power from the optimal GIHMGS.

Generation Summary	
Component name	Value & percentage
Solar Max 500RX A with Generic PV	10, 98,700 kWh/yr (35.8%)
Kohler 360kW Standby	20,070 kWh/yr (0.654%)
Enercon-53 (800kW)	19, 36,798 kWh/yr (63.1%)
Grid Purchases	14,009 kWh/yr (0.456%)
Total Production	30,69,577 kWh/yr
Consumption Summary	
Component name	Value kWh/yr & percentage
AC Primary Load	2, 42,079 kWh/yr. (10.6%)
Deferrable Load	15,285 kWh/yr. (0.668)
Grid Sales	17, 76,529 kWh/yr (77.6%)
Total Consumption	22,88,637kWh/yr.
Excess and unmet loads	
Quantity	Value kWh/yr & percentage
Excess Electricity =	7, 80,476 kWh/yr. (25.4%)
RF	94%
Unmet Electric Load	0

TABLE 6. Grid purchases and sales.

Grid	
Energy Purchased (kWh)	Energy Sold (kWh)
15,441	7,260,638
15,472	7,260,100
16,734	7,238,410
16,734	7,238,408
15,441	7,260,638
15,472	7,260,100
16,734	7,238,410
16,734	7,238,408
87,969	924,741
87,969	924,741
87,956	926,049
87,956	926,049

proposed design is 25 yr, the inflation rate is 3%, the annual rate of interest is 10%, the diesel price is 0.40$/L, the derating factor of the solar PV panel is 96%, the battery's lifetime is 12 yr, and the HH of the WT and lifespan is 40 m, 25 years respectively. The cost of the grid power is $0.145 per kWh, whereas grid power sells for $0.08 per kWh. According to an overview of the literature, real-time grid rates are as follows: The sale capacity is 800 kW, the yearly purchase capacity is 2000 kW, the capital cost of the grid is 10,000 $/km, the distance is 100 km, the rate of demand is 0.145$/kW/month, the mean outage frequency (1/yr.) is 80.00, the mean repair time is 10 hrs, the repair time variability is 50%, and the

TABLE 7. Greenhouse gas emissions for the proposed GIHMGS.

Pollutant	Quantity & Unit
CO2	27,153 kg/yr
Corban monoxide	96.9 kg/yr
Unburned hydrocarbons	5.26 kg/yr
Particulate matter	5.71kg/yr
Sulfur dioxide	83.1 kg/yr
Nitrogen oxides	246 kg/yr

CO^2 emission is 632.00(g/kWh). Table 6 shows the grid purchases and sales of the optimal system.

B. THE AC PRIMARY LOAD PROFILE OF THE GIHMGS

The solar PV system generates electricity throughout the day, with maximum production in the afternoon, as shown in Figure 13. The software performs 4404 hours annually, with an average output of 200 kW daily. The annual average of a real air temperature for Doddipalli was used with the temperature coefficient to explore the influence of air temperature on the electricity generated by the solar PV system.

Because of the negative temperature coefficient of the solar panel, the output power of the solar PV system drops as the temperature rises. Power production profiles and yearly energy generation costs are significant factors in evaluating energy system efficiency. Figure 13 shows the annual load profile, which shows that a lot of electricity is used from 7 a.m. to 12 p.m. every month. This is primarily due to the abundance of irrigation operations throughout the summer, when the weather supports the growth of most plants, such as crops and vegetables. The most significant load demand was recorded at roughly 62 kW during the year.

C. ELECTRIC SUMMARY

Table 5 gives the power generation and consumption of the optimal system. The total power production and consumption of the optimal system are 3.,69,577 kWh/yr and 22,88,637 kWh/yr. Also shows the excess amount of electricity produced and zero unmet load.

D. GREENHOUSE GASES EMISSIONS

Table 7 describes the details about the greenhouse gases emitted from the optimal GIHMGS, such as "carbon dioxide, carbon monoxide, un-burned hydrocarbons, particulate matter, sulfur dioxide and nitrogen oxides". Table 8 shows that the PV/WT//Grid configuration design produces CO_2 of 27,153 kg/yr into the air. It is lesser in quantity than other configurations such as PV/WT, PV/WT/BS and PV/BS, which were designed along with the proposed system. So, the optimal hybrid system designed by this research is good for the environment because it releases the least amount of carbon dioxide compared to any other system configuration. So the idea is to install the GIHMGS in the considered site in future

TABLE 8. Total NPC and Annualized Costs.

Total NPC						
Component	Capital ($)	Replacement ($)	O&M($)	Fuel ($)	Salvage ($)	Total ($)
Enercon E-53[800kW]	4,112,460.00	0.00	3,671,124.71	0.00	0.00	7,783,584.71
Generic 1kW Lead Acid	300.00	198.20	118.71	0.00	53.14	563.77
Generic Boiler	0.00	0.00	0.00	212,977.25	0.00	212,977.25
Generic Electrolyzer	2,275,000.00	678,796.32	2,700,604.58	0.00	117,236.71	5,537,164.20
Generic Converter	24,464.00	7,983.82	7,260.29	0.00	1,378.91	38,329.61
Grid	0.00	0.00	6,868,018.47	0.00	0.00	6,868,018.47
Hydrogen Tank	15,000.00	0.00	17,806.18	0.00	0.00	32,
SolarMax 500RK A	40,644.91	0.00	1,608.29	0.00	0.00	42,253.20
TLC	125,000.00	33,558.37	0.00	0.00	18,116.94	140,441.43
Overall System	6,592,869.31	720,536.71	469,495.70	212,977.25	136,785.70	6,920,101.87
Total Annualized cost						
Component	Capital ($)	Replacement ($)	O&M($)	Fuel ($)	Salvage ($)	Total ($)
Enercon E-53[800kW]	346,435,.26	0.00	309,257.00	0.00	0.00	655,692.26
Generic 1kW Lead Acid	25.27	16.70	10.00	0.0017,941.29	4.48	47.49
Generic Boiler	0.00	0.00	0.00	0.00	0.00	17,941.29
Generic Electrolyzer	191,646.90	57,182.07	227,500.00	0.00	9,876.07	466,452.91
Generic Converter	2,060.89	672.56	611.61	0.00	116.16	3,228.90
Grid	0.00	0.00	578,564.60	0.00	0.00	578,564.60
Hydrogen Tank	1,263.61	0.00	1,500.00	0.00	0.00	2,763.61
SolarMax 500RK A	3,423.94	0.00	135.48	0.00	0.00	3,559.43
TLC	10,530.05	2,826.97	0.00	0.00	1,526.18	11,830.84
Overall System	555,385.92	60,698.30	39,550.50	17,941.29	11,522.88	582,952.12

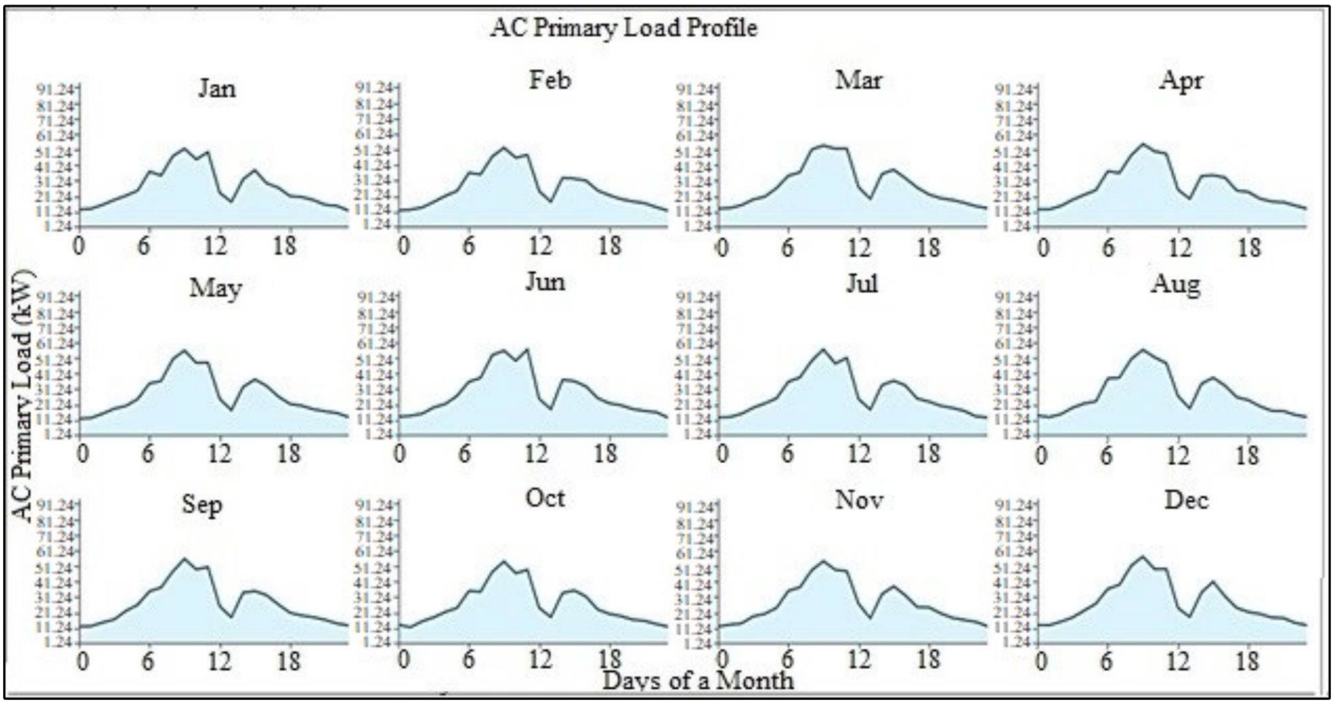

FIGURE 13. AC Primary Load Profile.

to help and fix problems caused by toxic gases released into the environment, also help to the country's economy.

E. TOTAL NPC AND ANNUALIZED COST

Table 8 shows the total NPC of the proposed system obtained from simulation. Here, the total NPC includes the total capital, replacement, O&M, Fuel and salvage cost of the system. Here, the optimal system obtained from simulation, which consists of solar max 500RX PV arrays of capacity 13.9 kW, enercon-E53 800kW (4), generic boiler, generic electrolyzer, generic large free converter of 94 kW capacity, hydrogen tank and TLC of 500kW. This proposed GIHMGS

TABLE 9. Comparison between existing systems and the proposed GIHMGS models.

Parameters	Existing Systems			Proposed Systems
Proposed System	PV/DG/BS/Grid [17]	PV/WT/Grid [10]	PV/DG/Biogas/Grid [15]	PV/WT/DG/BS/Grid
Solar radiation (kWh/m2/d)	4.88	5.403	4.8	5.13
Wind speed (m/s)	2.64	4.013	3	5.10
NPC ($)	692,694	86,394	960,469	5.19 M
LCOE ($/kWh)	0.280	0.55	0.260	0.0751
Renewable fraction (%)	72	—	68.30	97.8
Carbon emission (kg/yr)	32,905	3,484	—	9,755
Total load (kWh/d)	228,991	1,000,000	430	704.89

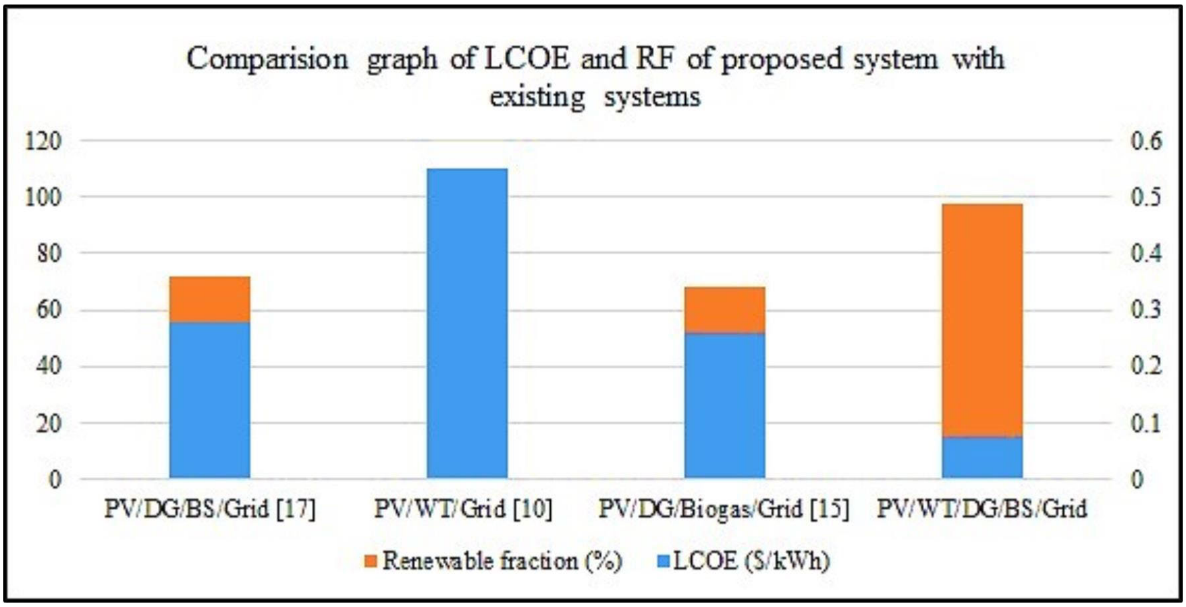

FIGURE 14. Comparison graph of LCOE and RF of proposed system with existing systems.

has the minimum NPC and lowest LCOE values, such as $6.92M and $0.0751/kWh respectively/ from the above it can be concluded that the NPC is minimum for the optimal design for the considered site. However, it is also important to note that the yearly expenditures for the components of this optimal system is expected to be $6,920,101.87. Table 5 shows the total annualized cost of the all components of the proposed system. However, it is also important to note that the yearly expenditures of the all components for the optimal system is expected to be $582,952.12.

F. VALIDATION OF PROPOSED SYSTEM RESULTS THROUGH COMPARISON WITH OTHER EXISTING MODELS

Several GIHMGS configurations are designed for electrification in the considered site using different RES, using the HOMER software. The simulation results demonstrate that the PV/WT/Grid system is the optimal GIHMGS, with the lowest NPC-$6.92M and LCOE-$0.0751 /kWh and the highest RF-97.8%. Table 9 depicts the comparative study of the proposed and existing designs. Hence, compared to other published research articles, the proposed GIHMGS was an optimal system for the LCOE of $0.0751/kWh. But, RF decides the optimal system if the LCOE of all systems is equal. Figure 14 shows the graphical representation of the LCOE and RF of the validation Table 9.

IV. CONCLUSION AND FUTURE SCOPE

In this research, an optimal GIHMGS was designed with minimum LCOE for the considered location. This system was identified as an optimal system from all the configurations generated by the HOMER software based on the LCOE, minimal NPC, and highest RF. Finally, the optimal system identified is PV/WT/Grid among all configurations that satisfy the electrical demand in the considered area while using less overall energy. The following are the important conclusions of this research:

1) The proposed system consists of Solar PV-13.9 kW, WT-800kW (4), Grid-9,999kW, Electrilyser-700kW, HTank-10 kg, TLC-500kW and 94kW of power converters. The optimal system comprises minimum NPC-$6.92 M, LCOE-$0.0715 /kWh and RF-97.8%.
2) Moreover, integrating RES with the optimal GIHMGS has provided several benefits including satisfying 100% of load demand with a surplus energy of 5.51% and lowering the release of harmful greenhouse gas (GHG) emissions into the environment.
3) Finally, the optimal GIHMGS can deliver at least 85% of the onsite power for the load at the selected site, with a renewable energy proportion of 97.8%. Moreover, the system is considered to be environmentally friendly due to its low carbon emissions.

A. FUTURE SCOPE

Due to the uncertainty of load demand and solar PV-wind power production, future work will focus on the uncertainty's importance on the system operation cost. Also, there is a possibility of enhancing the performance of the hybrid AC/DC microgrid system by applying multi-objective hybrid evolutionary algorithms, machine learning algorithms and deep learning algorithms.

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