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OPTIMAL DESIGN OF AN OFF-GRID INTEGRATED HYBRID RENEWABLE ENERGY SYSTEM FOR ELECTRIFICATION IN A REMOTE AREAS

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Abstract—Over time, the Off-grid generation system has gained credibility as a reliable energy source, catering to the electricity needs of rural regions. By integrating various renewable energy sources such as photovoltaic (PV) and wind depending on resource accessibility, it can be further enhanced as a dependable energy solution. With the growing electricity demand in remote areas, conventional energy sources struggle to meet the 24/7 requirement. Considering this surge, renewable energy emerges as a viable alternative, capable of meeting the increased load demand. By harnessing available technologies, a constant power supply can be ensured, and among the cost-effective and reliable options, off-grid technology stands out. Through this approach, power generation becomes feasible in remote locations using solar photovoltaic cells or wind energy, depending on the resource availability in those specific areas. The state of Jharkhand has been selected as a case study to assess the feasibility, economic viability, and technical compatibility of this off-grid system.

Keywords—PV, Wind, Off-grid, HRES (Hybrid Renewable Energy System), HOMER

I. INTRODUCTION

The term "off-grid system" refers to a system that operates independently of the main electrical grid. Specifically, it describes a photovoltaic (PV) system that is not connected to the central grid [1]. This system, also known as a standalone or mini grid, is capable of generating power and operating appliances without relying on external sources. Off-grid systems are particularly suitable for providing electricity to small communities. In countries with remote areas and sparse populations, where access to electricity is limited or non-existent, off-grid electrification systems offer a viable solution [2]. The off-grid system enables self-sufficiency, allowing individuals to live without depending on the grid or other centralized systems. In such systems, electrical energy generated by solar photovoltaic panels needs to be stored or preserved since the load requirements may differ from the output of the solar panels. Battery banks are commonly employed for this purpose[3].

The Off-grid system has emerged as a transformative approach to meeting energy needs in various parts of the world. Unlike traditional energy systems that rely on centralized grids, the off-grid system operates independently, providing power and electricity to communities and individuals without connection to the main electrical grid. This alternative energy solution has gained significant attention due to its ability to address the challenges of remote locations, underserved areas, and regions with limited access to electricity [4].

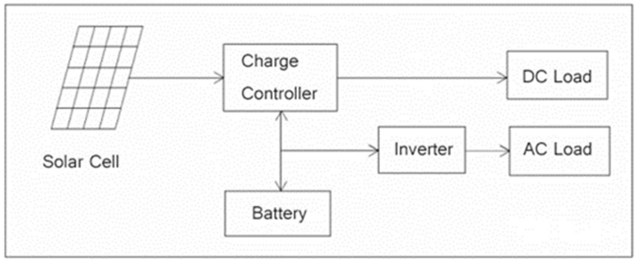


Fig. 1. Off-Grid Solar System

The off-grid system, also referred to as a standalone or mini grid, utilizes a combination of renewable energy sources such as solar photovoltaic (PV), wind, and biomass. By harnessing these clean energy technologies, off-grid systems generate electricity and enable the operation of appliances and devices, thereby offering a sustainable and self-sufficient energy solution [5].

One of the primary advantages of the off-grid system is its suitability for small communities and remote areas. In countries with vast territories and dispersed populations, establishing a centralized grid infrastructure can be economically and logistically challenging. The off-grid system provides an effective and scalable alternative, allowing communities to access electricity independently and meet their energy needs [6]. Furthermore, the off-grid system offers resilience and reliability in regions prone to power outages or unreliable grid connections. By generating and storing energy locally, communities are less susceptible to disruptions caused by grid failures or natural disasters, ensuring a continuous power supply for critical functions and daily activities [7]. Electrification in remote areas presents unique challenges due to limited access to traditional grid infrastructure [8]. To overcome these challenges, the optimal design of off-grid integrated hybrid renewable energy systems has gained considerable attention [9]. This literature review aims to explore the existing research and advancements in designing such systems for electrification in remote areas, focusing on their optimal configuration and performance.

In ref. [10-11] authors propose an optimal design method for a standalone hybrid power system using photovoltaic (PV), wind, battery, and fuel cell technologies. They employ an improved genetic algorithm to determine the optimal sizing of each component, considering factors such as load demand, renewable resource availability, and system reliability. The study demonstrates the effectiveness of the proposed method in achieving an optimized design for off-grid systems. In ref. [12] author present an optimal configuration design for hybrid power systems in remote areas using an improved particle swarm optimization (PSO) algorithm. The study considers multiple energy sources, including PV, wind, and diesel generators, to meet the load demand efficiently. The proposed optimization approach successfully determines the optimal combination of energy sources, component sizes, and operation strategies, resulting in improved system performance. In ref. [13-14] authors present an optimal design methodology for a standalone hybrid renewable energy system implemented in a remote village in Thailand. The study incorporates PV, wind, and battery technologies to meet the village's electricity demand. The authors utilize the HOMER software to analyze and optimize the system's configuration, resulting in an optimal design that meets the load requirements with high reliability and economic feasibility. Author perform a techno-economic analysis and optimal sizing of a hybrid renewable energy system for off-grid electrification in rural areas. The study considers PV, wind, and biomass technologies to meet the energy requirements of a rural community. Through simulation and optimization techniques, the authors determine the optimal sizing of each component and assess the economic feasibility of the proposed system [15]. The literature review highlights the significance of optimal design approaches for off-grid integrated hybrid renewable energy systems in electrifying remote areas. The studies discussed emphasize the use of advanced optimization algorithms, such as genetic algorithms and particle swarm optimization, to determine the optimal configuration, sizing, and operation strategies for such systems. These approaches consider factors such as load demand, renewable resource availability, system reliability, and economic feasibility to achieve optimal system performance. Future research can focus on incorporating emerging renewable technologies and exploring innovative control strategies to further enhance the efficiency and effectiveness of off-grid hybrid systems for electrification in remote areas.

This paper aims to explore the concept of off-grid systems, their benefits, and their applications in different contexts. Additionally, it will delve into the technical aspects, economic viability, and feasibility of implementing off-grid solutions, taking into account factors such as resource availability, infrastructure requirements, and the potential for scalability.

As the world continues to face energy challenges and seeks sustainable alternatives, the off-grid system presents an innovative and empowering solution. By providing electricity to underserved regions and fostering energy independence, it contributes to the goal of achieving universal access to reliable, affordable, and clean energy.

II. MODELLING OF AN OFF-GRID INTEGRATED HYBRID RENEWABLE ENERGY SYSTEM

A. Structural design of Proposed Model

To design a hybrid PV (Photovoltaic) and storage using HOMER (Hybrid Optimization Model for Electric Renewable), you can follow these steps:

1. Define the System Components: Determine the components required for your hybrid system, including PV panels, batteries for energy storage, inverters, and any other necessary equipment.
2. Assess Resource Availability: Analyze the solar and wind resources in the target location. Obtain data such as solar irradiance and wind speed to estimate the potential energy generation from both sources.
3. Define Load Requirements: Determine the electrical load requirements of the system. This includes estimating the power consumption and usage patterns of the connected devices.
4. Set System Parameters: Configure the system parameters in HOMER, such as the capacity and number of PV panels and wind turbines, battery capacity, inverter efficiency, and any other relevant parameters.
5. Define Control Strategy: Specify the control strategy for the hybrid system. Decide how the system will manage the power flow between the PV and wind sources, as well as the battery storage, to optimize the overall system performance.
6. Run HOMER Optimization: Utilize the optimization capabilities of HOMER to find the optimal configuration for your hybrid system. HOMER will analyze various

combinations of system components and control strategies to determine the most cost-effective and efficient design.

7. Analyze Results: Evaluate the results generated by HOMER, which will include information on the system's performance, energy production, fuel consumption (if applicable), and overall cost. Assess the feasibility and economic viability of the proposed design.
8. Refine Design: Based on the analysis of the results, make any necessary adjustments to the system design. Modify the parameters, such as component sizes or control settings, to improve the performance and optimize the system further.
9. Validate and Implement: Validate the design through further simulations or real-world testing, if feasible. Once validated, proceed with the implementation of the proposed hybrid PV and wind system.

It's important to note that HOMER provides a powerful platform for system optimization, but the specific design and configuration will depend on the project requirements, available resources, and desired outcomes. Consulting with renewable energy experts or using HOMER's user guide can provide further guidance and ensure a successful design of your hybrid system.

Fig. 2. Praposed Model

B. Load Calculation (Input Data)

For the off-grid PV system, a residential site is selected which is located in Bahadurpur Koderma, Jharkhand, India (24°28.1' North, 85°35.6' East). The Consumption of load in India primarily depends on the weather, and it is varying month by month. That is why the load is calculated individually for each month.

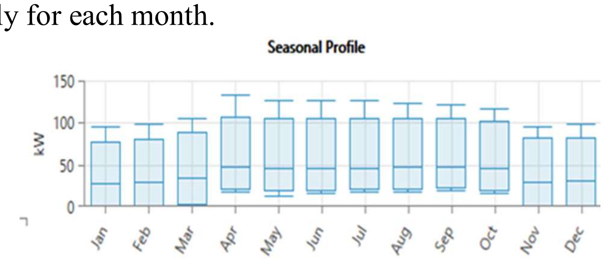


Fig. 3. Seasonal Load Profile

C. P.V. Details and specifications

Solar radiation is used to generate to the electrical energy by converting the solar photon energy into the electrical energy with the help of Solar cells. The combination of solar cells in series and parallel are called solar panel. The components used for the solar energy generation structure are solar (PV) panels, Inverter, Cables and batteries etc. Here in Table-I , the costing parameters according to specifications have been discussed of photovoltaic.

TABLE I. COSTING DETAILS FOR P.V. [16]

Description	Specifications
Capacity (kilowatt)	0.330
Capital Cost (Rs.)	9570
Replacement (Rs.)	9570
O & M (Rs/ Year)	95.70
Lifespan (Years.)	25
Derating Factor	0.88
Temp. Coefficient	-0.410
Efficiency at standard test condition (%)	17.2
Ground reflectance (%)	20

D. Solar Resource

Latitude & Longitude data for a Residential Houses, Bahadurpur Koderma, Jharkhand
Latitude : 24°28.1' North, Longitude : 85°35.6' East
Time Zone – (GMT+5:30) India
The radiation varies from season to season, i.e., 3.990 kiloWatt-hour/ meter square /day to 6.688 kiloWatt-hour/ meter square /day and the yearly 5.07 kiloWatt-hour/ meter square /day is the yearly average radiation at the selected. Clearness index varies from 0.386 to 0.628.
Figure 4 shows the GHI (Global Horizontal Radiation) at a selected site, and it is taken from NREL.

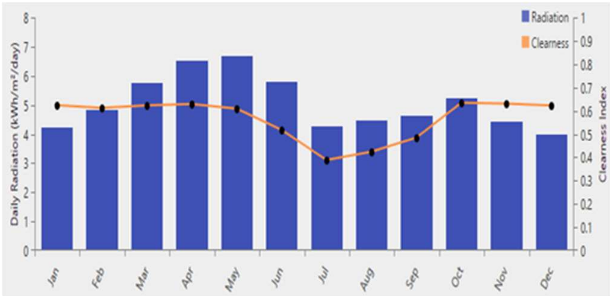


Fig. 4. GHI and Clearness Index

E. Battery Specifications

The general specification and price parameters of the storage device are displayed in Table-II The parameters are used for simulation and optimization purpose in HOMER.

TABLE II. COSTING PARAMETERS OF BATTERY [17]

Description	Specifications
Rating (Ah)	150
Voltage (V)	12
Capital Cost (Rs.)	12850
Replacement (Rs.)	11565
O & M (Rs.)	128.50
Life Time (Years)	6
Nominal capacity (kilowatt-hour)	2.04
Lifetime throughput (kilowatt-hour)	2177.90

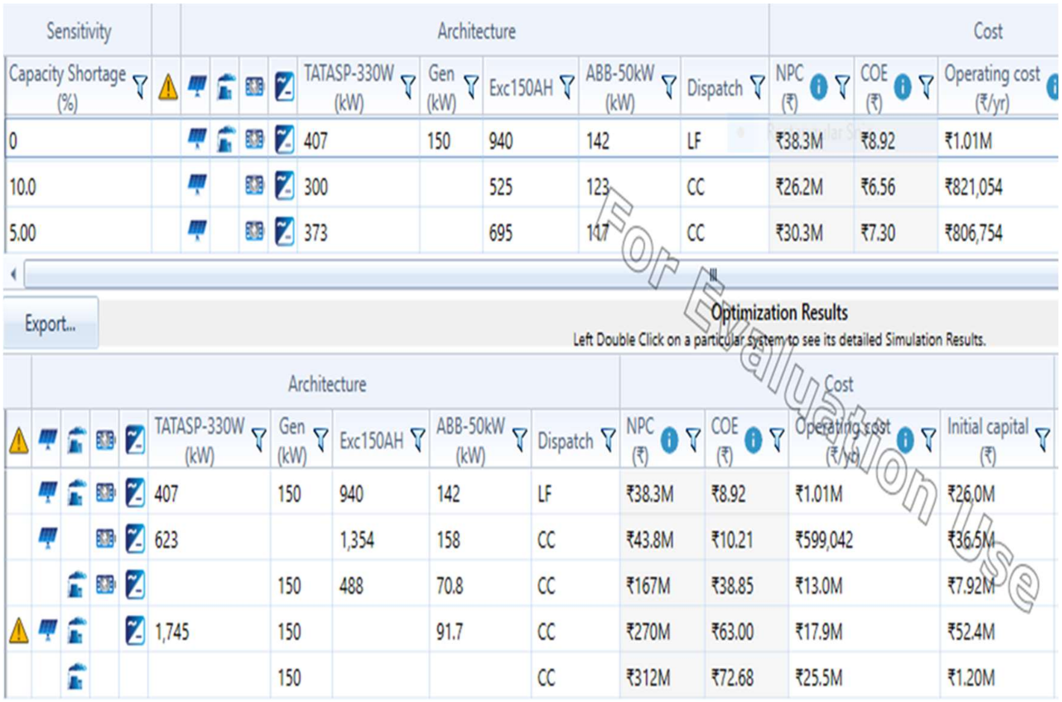
F. Converter Specifications

The converter is a device, converts A.C. into D.C. and D.C. into A.C. It is a combination of rectifier and inverter. Different specifications and costing parameters for the converter are specified in Table-III

TABLE III. COSTING PARAMETERS OF CONVERTER [18]

Category	Description
Size (kilowatt)	50
Capital Cost (Rs.)	3,19,500
Replacement (Rs.)	3,19,500
O & M (Rs. / Year)	159.75
Life Time (Years)	15
Efficiency (%)	98.40

III. SIMULATION AND RESULTS



Capacity Shortage (%)	TATASP-330W (kW)	Gen (kW)	Exc150AH	ABB-50kW (kW)	Dispatch	NPC (₹)	COE (₹)	Operating cost (₹/yr)
0	407	150	940	142	LF	₹38.3M	₹8.92	₹1.01M
10.0	300		525	123	CC	₹26.2M	₹6.56	₹821,054
5.00	373		695	117	CC	₹30.3M	₹7.30	₹806,754

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Optimization Results

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

TATASP-330W (kW)	Gen (kW)	Exc150AH	ABB-50kW (kW)	Dispatch	NPC (₹)	COE (₹)	Operating cost (₹/yr)	Initial capital (₹)
407	150	940	142	LF	₹38.3M	₹8.92	₹1.01M	₹26.0M
623		1,354	158	CC	₹43.8M	₹10.21	₹599,042	₹36.5M
	150	488	70.8	CC	₹167M	₹38.85	₹13.0M	₹7.92M
1,745	150		91.7	CC	₹270M	₹63.00	₹17.9M	₹52.4M
	150			CC	₹312M	₹72.68	₹25.5M	₹1.20M

Fig. 5. Optimization Result

TABLE IV. COMPARISON OF DIFFERENT BEST COMBINATIONS OF RESOURCES

S. No.	Optimal Combinations	Components Details	Total NPC (Rs.)	LCOE (Rs./kilowatt-hour)
1	PV-DG System with 0% Capacitive Shortage (Case-I)	PV-407 kW DG-150 kW Converter-142 kW Storage- 12V , 150 AH Battery Qty-940	₹ 38,256,170	₹ 8.92
2	Standalone PV System with 5% Capacitive Shortage (Case-II)	PV-373 kW Converter-117 kW Storage- 12V , 150 AH Battery Qty-695	₹ 30,308,740	₹ 7.30
3	Standalone PV System with 10% Capacitive Shortage (Case-III)	PV-300 kW Converter-123 kW Storage- 12V , 150 AH Battery Qty-525	₹ 26,222,710	₹ 6.56

On the basis of above the best optimized combination obtained by homer is shown below:
An off-grid solar photovoltaic energy system with converter and battery storage is planned for residential load of a village ,Bahadurpur Koderma, Jharkhand, India.

The coordinate of the site is 24°28.1'N, 85°35.6'E. The Proposed system is optimised and examine with the help of HOMER Pro software.

Top three result of the optimised system has been explained in Chapter 5. The result of the optimised system is shown in Fig 5.

The system was developed and optimised for the climate conditions of the site. The off-grid solar photovoltaic energy system shows the meaningful and optimal result among all the combinations in terms of NPC and COE generated by simulation are compared in Table-IV.

IV. CONCLUSIONS

The highlights of above study are as follows:

a) Due to the availability of an adequate amount of solar energy, the first optimum combination is DG connected P.V. with converter and with batteries. It is the most reliable combination due to presence of DG. The NPC of the off-grid DG-PV system is ₹ 38,256,170 and COE is ₹ 8.92.

b) HOMR obtains the best combination of standalone PV system with storages and with converter. It has 5% capacitive shortage. It has the second least, NPC and COE, which is ₹ 30,308,740 & ₹ 7.30 respectively.

c) The third combination is obtained by simulation is P.V. alone with converter and batteries. It has 10% capacitive shortage. It is off grid system. NPC and COE of system is ₹ 26,222,710 & ₹ 6.56 respectively.

d) After evaluation of the above result, standalone PV System with Storages has recommended because the Solar PV system gives 100 % green energy as it emits 0% of pollutants and reduces the dependency on the grid. With having DG , systems become more reliable but it also become less economical and less environmental friendly.

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