Moving Towards Self Reliant Microgrids in Indian Scenario

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Abstract

An electrical power system is among the most critical infrastructures which are crucial for the sustainable development of a nation. The progress of a country like India cannot be thought of without being self-sufficient in the rural areas where about 65% of the population resides. The cost of the power grid is increasing and the communities should search for better options from within their available resources to generate energy. Microgrid (MG) formation shall lead to a self-reliant power system providing low-cost energy for consumers. Environmental factors should also be considered while designing a MG. Renewable energy plays a pivotal role in the formation of MGs in rural regions where these sources are available in abundance. For investigation purposes, three villages from Jharkhand, India, are selected in this study. These villages have different types of renewable energy resources and loads within their jurisdiction. The installation of renewable energy sources will make the villages more self-reliant. HOMER software is used

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during the analysis of the system by considering the renewable energy contribution and subsidy as a factor. Without subsidy, the combination of the system is intended to operate at Rs. 5.32/kWh and with 69.1%, renewable energy sharing of the total load. The best configuration results in a minimum cost of energy (COE) of Rs. 4.92/ kWh (with subsidy) which is less than utility cost (Rs. 6.25/kWh) and has a share of 63.1% of renewable energy.

Keywords: Renewable energy sources, micro-grid, HOMER, cost of energy, payback period, optimization.

1 Introduction

India is the third-largest producer and consumer of electricity in the world with generation predominantly based on the burning of coal [1], thus being one of the largest emitters of GHG in the world. The per capita energy consumption is an indicator of the overall progress of the nation. The growth in per capita energy consumption of India over the years is given in Figure 1. Contribution of non-conventional sources and conventional sources with an installed power capacity of India are 91GW and 284GW respectively, taken @ December 2020 [2, 3], and its combination is shown in Figure 2(a) and 2(b).

The most remote regions in underdeveloped countries still lack electric supply. The self-sufficiency of a country like India cannot be thought of

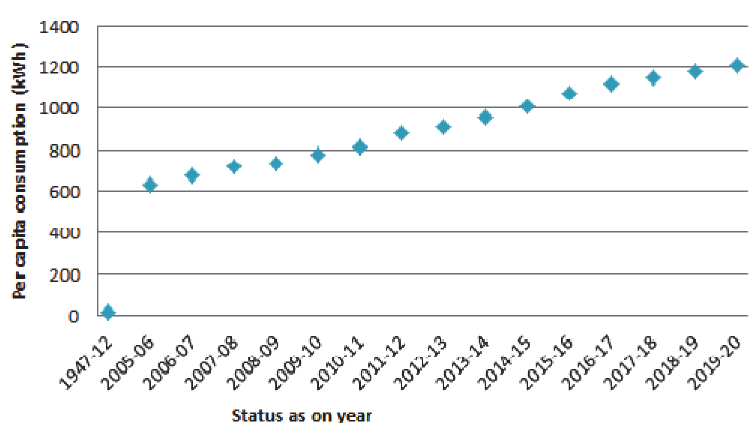


Figure 1 Growth in per Capita Energy consumption in India [2].

(a) RES distribution (b) Conventional energy type distribution

Figure 2 Share of renewable and non-renewable energy @ India.

without the self-sufficiency of the rural areas where about 65% of population resides. Since the rural area is dominated by agriculture, farm residue and animal wastes are invariably available in almost all the villages. The renewable energy based power generation is increasing rapidly but still, the power generation in India and many other countries is dominated by the fossil fuels. MG is a small power system that works in independent or grid-connected mode and consists of its generation and load with limited transmission. These power system modules increase the existing power system's reliability, security, and diversification. It also decreases carbon output while saving operating costs [4]. MG offers a possible alternative for rural electrification. The installation of an AC MG eliminates any compatibility issues with the villages' existing AC loads, as well as the ability to freely exchange power with the utility grid. Installation of a stand-alone MG necessitates a study of demand and energy generation resources.

A hybrid Renewable Energy Sources (HRES) is the combination of unconventional energy resources like solar, wind, biomass, small hydro, energy storage or, diesel generator to deliver electrical power [5]. Renewable Energy Sources (RES) with energy storage are applied for rural electrification where the grid connection is not possible. RES is constantly regenerated by natural processes and should be used to the maximum extent possible. When compared to conventional sources, these sources are less expensive to operate and do not contaminate the environment [6–8].

Economic and reliability constraints dominate the deployment of electricity to rural areas. The analysis of these factors determines the performance of the system during the operation mostly in renewable energy. An analytical approach that is based on algebraic equations is proposed in [9] for determining PV array area and appropriate battery storage (BS) capacity. In terms of reliability and affordability, the storage size is optimum for a standalone PV system. The evaluation of cost-benefit and Green House Gas (GHG) emission of a hybrid system model for electrifying a remote rural community is performed in [10]. The HOMER software is used to compare various resources.

[11], a discussion related to the sizing and siting of MGs with a hybrid system having WT/PV/FC/ hydrogen tank in small residential building is presented. Reliability, power quality, power loss, and uncertainty of solar irradiance, load, load growth and wind speed are considered during analysis. In addition, demand response of controllable loads, changing the capital cost of RES and ESS placement are considered using PSO techniques. It was observed that an increase in load will affect the total cost of the system.

Load variation and uncertainty in long periods have an impact on techno economic analysis for power system planning precision. Multi-Layer Perceptron - Artificial Neural Network (MLP-ANN) as a deep-learning algorithm is applied in [12] for the load forecasting in MG planning. Investigating the optimal system configuration and electricity pricing strategy for MG through HOMER software is presented in [13]. The analysis shows that the combination of PV, WT and converter in the grid-connected operation mode of MG is the most economical configuration, excluding ESS for selected cities. The cities selected have higher potentials of wind speed and solar irradiance characterized by lower NPC and COE. Alternative energy generation in countries like Ethiopia is of prime importance which is highlighted in [14]. It presents a combination of solar PV and wind energy to supply electricity to Debre Berhan City. The simulation is done using MATLAB.

The authors in [15] discussed the integration of RES and its effects on the electricity market for optimal operation of the system. Various uncertainties like the departure time, the arrival time and the traveled distance of Electric Vehicles (EV) along with WT and PV power production are forecasted using Copula method. They conclude that the high integration of renewable energy will reduce MG energy costs. In [16], the resilience of the power system after disturbance/fault which occurred due to weather changes is highlighted. NPC and COE are considered for economic cost analyses, while aiming to increase the resiliency of the system, using HOMER software. Grid-connected MGs were found to be more economical than Traditional Generators (TG) as a standby. A similar study is presented in [17]. A techno economic analysis for establishing microgrid is performed. This paper also relies on HOMER software for furnishing their results.

As stated and observed in [18], electrification of remote villages can be solved through RES integration. The integration of RES has small environmental effects compared to non renewable energy. The optimal point of operation for the integrated RES to provide reliable and cost-effective energy is determined using HOMER. HOMER considers external disturbances and sensitivity like technical snags or climatic changes while providing the output. Analysis of different sensitivity parameters affects the overall optimal combination.

Hybrid energy system optimization that is connected to the grid by considering electric and thermal load growth rates is researched up on in [19]. Different reviews are also investigated regarding load types (electrical and thermal load) and dynamic planning scenarios in these case studies. The economic analysis is evaluated using NPC and COE for different plant configuration. The fittest point is selected by comparing their mode of operations viz., grid connected and standalone. A grid connection with WT system, converter, and boilers is the most economical configuration in grid-connected mode is more economical and environmentally friend than an off- grid system for the selected site.

HOMER software is preferable than heuristic methods as discussed in this study; in heuristic methods, parameter tuning is a challenge, they are typical, not straight forward to check the achieved solution is globally optimal or not, and computationally expensive (long running time). The feasibility of grid connection or off-grid is determined by break even point, the distance at which the total Net Present Cost (NPC) of grid extension and installing a stand-alone system are equal, is discussed in [20]. For the selected case study, the grid extension is feasible upto 31km transmission line with the presented components market cost. The evaluation is done HOMER software to determine the feasible point. Designing of an on-grid microgrid is also considered in [21]. However, the objective of this research is directed towards long term load demand prediction.

Due to its simplicity and flexibility to Renewable energy optimization analysis, HOMER software is used in this research. It can design and evaluate technical and financial aspect for remote, optimizes the cost, stand-alone and distributed generation applications,shows system configurations, simulates energy systems and provides sensitivity analyses [22]. An analysis is performed based on energy cost and integration of renewable sources in the rural region of Baheya, Ulatu and Karmadhippa, India. Different options are considered for improving the electric supply of the concerned region with available resources and grid connection. The villages under consideration are subjected to irregular power supply from the grid. This paper tries to explore the different possibilities and sources of energy generation which will provide energy at different times. Energy storage is not considered as it requires maintenance which may not be provided as per requirement.

Contributions of this paper:

- A Methodology is proposed for designing and setting up a grid connected MG in rural area.
- Proposed research work presents a concept of forming a MG with a cluster of three villages.
- Three RES, viz. solar, biomass, and hydro (waterfall) have been considered.
- To minimize the cost, an AC MG-based system, grid-interactive AC MG without energy storage has been considered.
- An analysis related to the NPC and COE of the hybrid plant is established which includes a payback period involving inflation costs.

The sections in this paper are organized as: Section 2, deals with the modeling of Hybrid renewable energy considered in paper. Section 3 discusses about the case study, methodology and problem formulation of the system. Section 4 deals with the Resource Potential and Load Distribution analysis. Section 5, deals with the result and discussions including different evaluation parameters. Last section is used for concluding the paper.

2 Modelling of Hybrid Renewable Energy Systems (HRES)

The available energy resources that are environment-friendly and techno-economic are considered for the analysis. For the case study three villages from Jharkhand are considered that have abundant renewable resources to have a reliable power supply without any scheduled power cuts. As a step towards self-sufficiency in electrical power, locally available resources like solar, agricultural waste, and river/water have been considered. These energy sources have been considered as they do not pollute the local environment.

The research approach aims at economic and self-reliant (to the extent possible, otherwise utility grid connectivity is already available) power supply to the villages using locally available environment-friendly resources. The AC MG which is capable of interacting with the grid has been considered, for exchanging power with the utility. The AC MG will match well with the

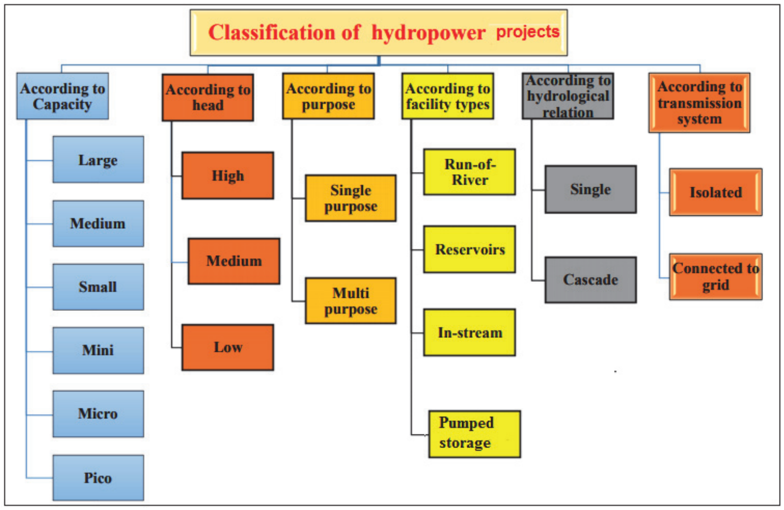


Figure 3 Classification of small hydropower projects.

existing light fittings, fans, coolers, pumps, motors, and other appliances in the villages fed by the AC utility grid. To minimize the cost of energy, the excess energy generated by the renewable sources will be supplied to the utility grid.

2.1 Small Hydro Power

Water at a higher level possesses potential energy and when it flows downwards, the potential energy is converted into kinetic energy. The potential and kinetic energy of water are utilized to rotate the prime mover i.e. hydro turbine, which converts pressure into mechanical shaft power for generating energy. The hydropower project is classified depending on different aspects as shown in Figure 3. The overall power output of a hydro generating unit (P_{HP}) (kW) is calculated using Equation (1) [23].

$$P_{HP} = \frac{\eta_o \times \rho \times g \times Q \times H_n}{1000} \quad (1)$$

Where η_o: overall efficiency of a generating unit. ρ: Water density, (1000 kg/m^3)
g: acceleration due to gravity, 9.81 m/s^2
Q: flow rate of water passing through a turbine, m^3/s
H_n: net water head, m

E_{HP} (t) is the generator energy yield, kWh at t^{th} hour is calculated using Equation (2)

$$E_{HP}(t) = P_{HP}(t) \times t \tag{2}$$

where t: time step, hour.

2.2 Solar PV Power

A solar photovoltaic (PV) system converts the raw energy from the sun into electrical power. The output power of PV depends on the number of solar modules, fill factor, open-circuit voltage, and short circuit current of the module. The power output of the solar PV system (P_{pv}) is computed for every hour as given in Equation (3) [23].

$$P_{pv} = \frac{N_m \times V_{oc}(t) \times I_{sc}(t) \times FF(t) \times \eta_{oB}}{1000} \tag{3}$$

where, N_m: number of modules (i.e. Series and Parallel),
V_{Oc}: open-circuit voltage, (V)
I_{SC}: short circuit current, (A)
FF(t): form factor of the solar panel

The energy yield (kWh) of a solar PV system (E_{PV}) in kWh is calculated as Equation (4).

$$E_{PV}(t) = P_{Pv}(t) \times t \tag{4}$$

2.3 Biogas Generator (BGG)

In a biogas generator, the slurry of cattle dung is fed into the digester. From the upper portion of the digester, the flow of gas is controlled by using the pressure valve. A desulphurization unit is provided to remove the sulphur from the gas. This gas can be used for cooking and generate electricity. The electric power that can be harvested from biogas is calculated using Equation (5) [23].

$$P_{BGG}(t) = \frac{T_g \times \eta_{oBG}(t) \times CV_{BG}}{860 \times t} \tag{5}$$

where, T_g: total gas yield for electricity in (m^3/d),
CV_{BG}: the calorific value of biogas generator in (kcal/m^3),
η_{oBG}: efficiency of biogas generating system in (%).

The energy yield (kWh) from biogas generator at the t^{th} hour is given by Equation (6).

$$E_{BGG}(t) = P_{BGG}(t) \times t \tag{6}$$

3 Case Study

3.1 Methodology

Renewable energy resources, primarily solar, biomass, and hydropower, are abundant in India's rural areas. These resources' energy can be used to meet local demand in part or entirely. Installing and maintaining long-distance transmission lines in sparsely inhabited rural areas is expensive, therefore utility grid access may be limited. To reduce those problem, local energy resources must be used to generate electricity in such regions. The methodology used during the analysis of HRES is summarized in Figure 4.

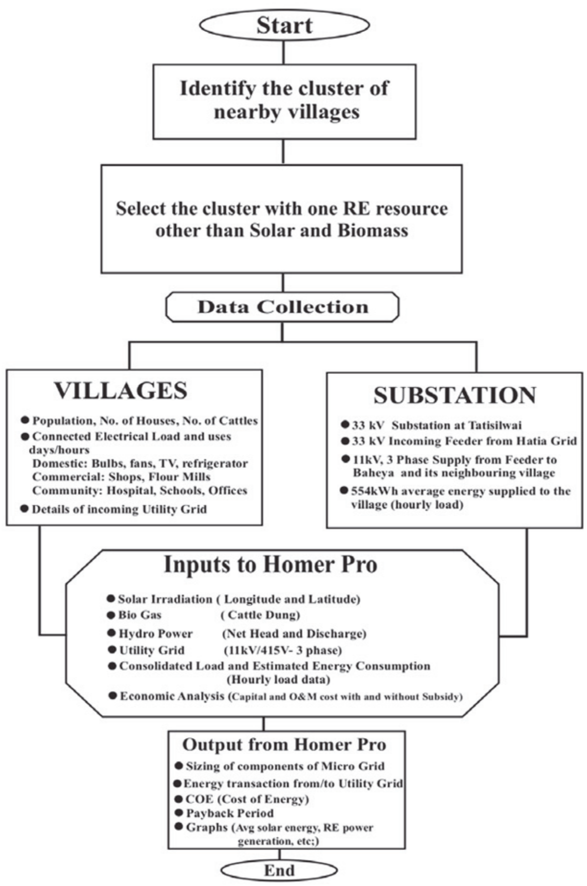


Figure 4 Flow chart of the methodology developed.

3.2 Problem Formulation

The goal of this project is to make the villages' power system more self-sufficient by operating it at reduced costs and with a bigger contribution of renewable energy resources. Different approaches for determining the per-unit cost of electrical energy produced are used in power generation economics. Cost of Energy (COE), cost of generating one unit of energy, 1kWh and Total Net Present Cost (TNPC) that calculated by subtracting the present values of all cash outflows, such as capital investments, operation and maintenance charges, and fuel expenses, from the present values of all cash inflows, such as scrap sales are the common. The cost of energy is formulated in Equation (7) [24].

$$COE(Rs/kWh) = \frac{TAC}{\sum_{t=1}^{8760} E_{(gen)}(t)} \tag{7}$$

Where TAC = TNPC × CRF
$E_{(gen)(t)}$: electrical energy yield at the tth hour (kWh),
TAC: Total Annualized Cost of the system(Rs)
CRF:capital recovery factor calculated using Equation (8).

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{8}$$

n: project lifetime, (yr)
i: interest rate per year, (%).

The overall objective function of the system is formulated in Equations (9) and (10) with its constraints from Equations (11)–(13).

$$Minimize\ F(COE) \tag{9}$$

Such that:

$$Max(E_{(gen)}(t)) = E_{pv}(t) + E_{BM}(t) + E_{HP}(t) \pm E_{grid}(t) \tag{10}$$

Subject to constraints

$$0 \leq P_{PV} \leq P_{PV}max \tag{11}$$

$$0 \leq P_{HP} \leq P_{HP}max \tag{12}$$

$$0 \leq P_{BG} \leq P_{PG}max \tag{13}$$

Where P_{PV}max, P_{HP}max, and P_{PG}max are the maximum possible generation limit for solar PV, hydro, and biogas, respectively.

HOMER is a software that simulates energy systems, displays system configurations, optimizes costs and performs sensitivity analysis. It uses energy balance calculations at a predetermined time step to simulate the operation of a system and determines the flow of energy to and from each system component for each time step by comparing the electrical load demand with the system's capacity. It determines whether the configuration is viable and calculates the cost of installation and system operation during the project's lifetime. HOMER is used for simulation of hybrid systems in real time.

Solar irradiation, hourly electrical energy consumption, biogas plant, hydro system, etc are all considered during the simulation. Data on capital costs and operating and maintenance costs with and without subsidies are also calculated for economic analysis. Furthermore, based on the information provided by the user, HOMER creates a variety of component combinations. It simulates each combination in order to reduce the cost of the system while adhering to the modeler's requirements. The HOMER pro is used to conduct a detailed techno-economic analysis of HRES. The HOMER optimizer and HOMER Search Space are the optimization algorithms used in this software. The HOMER optimizer runs a proprietary derivative-free algorithm to simulate all possible system configurations in order to find the least expensive one. The grid search algorithm is used by the HOMER search space algorithm [25].

The following are the steps that make up the HOMER software's step-by-step operation.

- Step-1: Fill in technical details like load demand, solar irradiation, biogas, hydro, and converter.
- Step-2.Fill in the financial information for solar PV arrays, biogas, hydro, the grid, and converters.
- Step-3. After simulating and optimizing the solution, perform a sensitivity analysis.
- Step-4. Obtain the results.

To minimize the cost of energy, it may generally not be economical to meet all the energy demand from the locally available resources of energy. Instead, power may partially be drawn from the utility grid, at least during peak hours. During the analysis, it was observed that the majority share of energy is from renewable resources which would also help reduce GHG emissions.

4 The Distribution of Loads and Resource Potential

The identified and clustered of villages have renewable energy resources such as solar and biomass (agricultural waste & cattle dung), in abundance. Because fossil fuel-based energy dominates utility power, the goal of this study is to design a low-cost, reliable and ecofriendly hybrid renewable energy system model that uses locally available. During the analysis, three villages, Baheya (23.36°N, 85.48°E), Ulatu (23.38°N, 85.46°E), and Karmadhippa (23.37°N, 85.47°E), Jharkhand, India are selected. These villages are geographically very close to each other. Their locations and other details are presented in Figure 5.

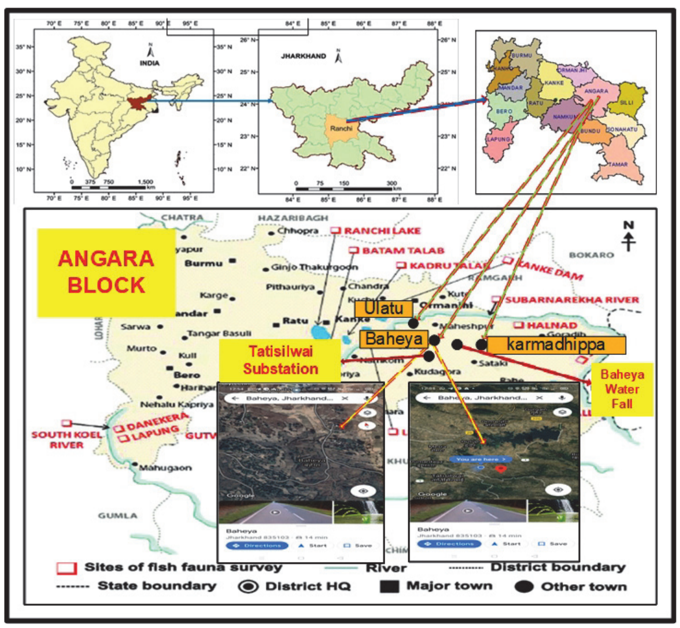


Figure 5 Cluster of Villages with sub-stations and waterfall location.

4.1 Load Profile of All Villages

The total average daily load curve for villages is presented for: Summer and Winter in Figure 6. The data has been collected in person, on 2–4 May 2020 for Summer and on 20–28 December 2020 for Winter. Due to variation in temperature, the need for cooling systems is higher during summers. The cluster of villages receives the power supply form the 33 kV Tatisilwai sub-station which is fed from the 220 kV/132 kV substation at Hatia, Ranchi city. The 33 kV/11 kV substation at Tatisilwai transmits power to the Baheya substation through an 11 kV feeder.

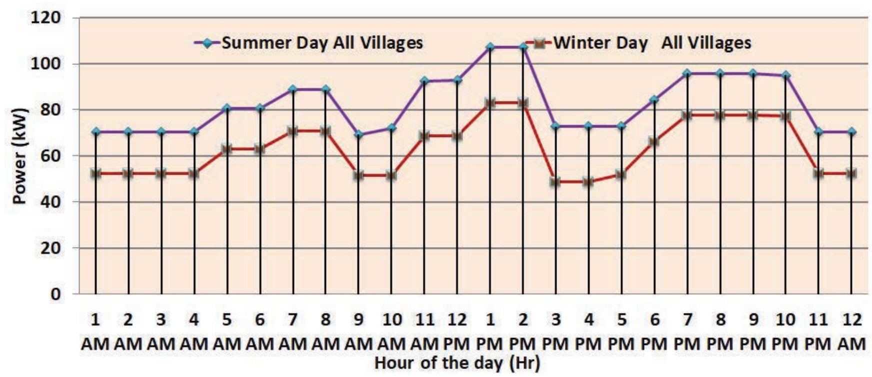


Figure 6 Seasonal load for three Villages, Summer Surveyed @ May 2–4, 2020 and Winter Surveyed @ Dec 20–28, 2020.

4.2 Solar PV Generation

The cluster of three villages, namely Baheya, Karmadhippa, and Ulatu are in the vicinity of one another. Hence, the solar energy and temperatures of the Baheya village obtained can be used for Karmadhippa and Ulatu villages also. The average solar radiation for those villages is shown in Figure 7.

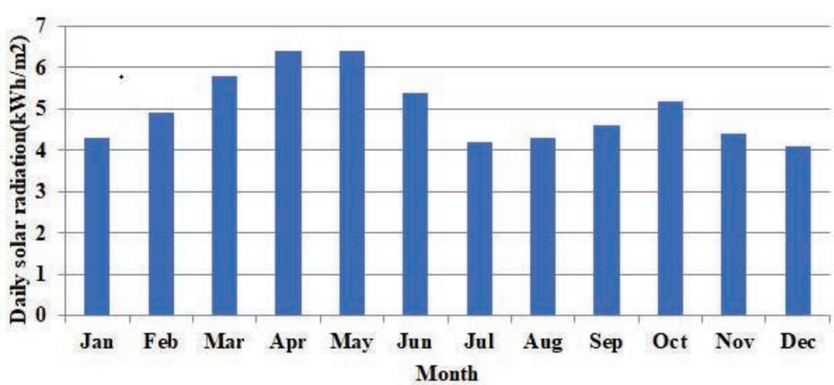


Figure 7 Monthly average solar energy from [26], @ 23.36°N – 85.48°E.

Table 1 Consolidated biogas potential from cattle dung of 3-villages

Animals	Cattle Number	Availability (kg/cattle/day)	Total Dung (kg/day)	Biogas Yield (m^3/kg)	Total Potential (m^3/day)
Cow	465	10	4650	0.038	176.5
Buffalo	420	14	5880	0.04	235.0
Goat	230	0.5	115	0.074	8.5
Total	1115	—	10645	—	420

Table 2 Water resource near to village Baheya

Parameter	Values
Head	20 m
Discharge (Q)	0.045 m^3/s
Efficiency	80 %

4.3 Biogas Generation

Common cattle like cows, buffalo, and goats are available in these villages. They produce dung which can be used for Biogas generation. The cattle dung resource availability of three villages is summarized in Table 1.

4.4 Hydropower Generation

The Jharkhand state of India is rich in perennial streams from small hills. The Baheya stream near Baheya village is considered for power generation by establishing a micro hydro-power system. The required data and water potential for micro hydro-power generation is shown in Table 2.

5 Results and Discussion

The proposed research work presents a study on the viability of installing an optimal combination of renewable energy sources in the rural villages of Jharkhand state of India. The villages are combined as a cluster for better distribution of available sources. The installation of these renewable energy sources not only helps these villages become self reliant in power supply but also is an environment-friendly way of energy production. Connecting the system to the grid will allow balance of power flow and provide reliability to the system. In this section, we analyze the different aspects and their outcomes for the problem at hand.

The villages have a combined population of 1594, living in 335 households. The connected load is classified into three categories, namely commercial, domestic, and community. The energy consumption for the three villages

Table 3 Specifications of micro hydro power system

Parameters	Unit	Value
Rated capacity	kW	7.5
Rated discharge	L/s	45
Net head	m	20
Efficiency of the MHP	%	80
Capital Cost	Rs.	7,500,000
Annual O & M Cost	Rs.	25,000
Lifetime of components	year	25

Table 4 Specifications of biogas plant

Parameters	Unit	Value
Rated capacity of the Biogas system	kW	3
The conversion efficiency	%	50
Lifetime of civil work	Year	25
Lifetime of engine generator	h	20,000
Cost of engine and electric power generating unit	Rs./kW	15,000

Table 5 Specifications of solar PV panels at standard test conditions

Parameters	Unit	Type
Rated capacity of Solar PV	kW	60
Number of solar cells in panel	Nos.	72
Current at maximum power	A	6.71
Voltage at maximum power	V	32.2
Short circuit current	A	7.24
Open circuit voltage	V	39.4
Derating Factor	%	80
Lifetime	Year	25
Initial cost of Solar PV per kW	Rs.	30,000
O & M cost per year	Rs.	4,000

Table 6 Specifications of converter

Parameters	Unit	Type
Converter rating	kW	45.3
Converter efficiency	%	95
Lifetime	year	15
Converter cost per kW	Rs.	7500

is 1598 kWh/day (summer) and 1395 kWh/day (winter). The technical specifications and cost of components used for modeling of the MG for the cluster of villages are extracted from HOMER [22] and are given in Tables 3–6. The model of overall system is shown in Figure 8.

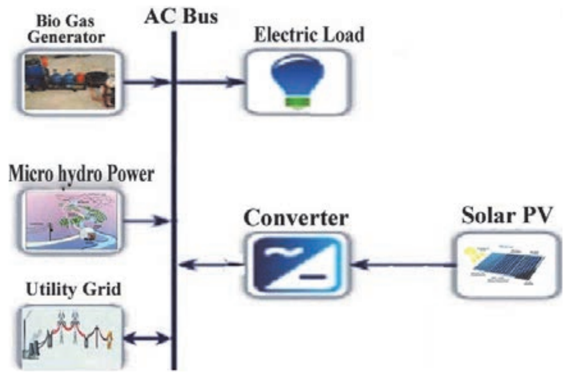


Figure 8 Schematic diagram of HOMER based AC micro grid.

Table 7 Monthly energy transactions between MG and utility

Month	Energy Purchase From Grid (kWh)	Energy Sell to Grid (kWh)	Net Energy Transaction (kWh)	Peak Load (kW)	Energy Charges (Rs)
January	4894	6223	−1329	20	−7364
February	5531	4762	769	22	4230
March	6143	4525	1618	22	8897
April	7794	2764	5030	27	27667
May	8086	2263	8523	27	32024
June	8694	1138	7556	27	41558
July	5032	1913	3119	20	17155
August	5008	2095	2914	19	16024
September	5026	2623	2403	19	13217
October	6143	5106	1021	20	8897
November	5531	4761	770	22	4230
December	4897	6229	−1332	20	−7327

The energy purchased from the utility grid and energy sold to the utility grid in kWh per month with peak load is shown in Table 7. The maximum power purchased from the utility grid is in April and May, while the maximum energy sold to the utility grid is in January and December.

5.1 Sensitivity Analysis

Sensitivity analysis is a technique for determining how many differences in the input values for a specific variable will affect the outcome of a mathematical model. This analysis examines the sensitivity of acceptable variants in order to find the most cost-effective option. Currently, the people

Table 8 Sensitivity variables for resources

Solar Scaled Average ($kWh/m^2/day$)	Hydro Scaled Average (L/s)	Cost of Energy (Rs/kWh)
4.5	40	6.25
4.5	50	5.90
5.0	40	5.65
5.0	50	5.32

Table 9 Cost of components of MG system (without subsidy)

MG Components	Cap Cost (Rs.)	O&M (Rs./yr)
7.5kW MHP generator	7500000	25,000/year
60kW solar PV	1800000	4000/yr
3kW Biogas	45000	43800/yr
45.3kW Converter	339609	500/yr
Total	9684609	73300/yr

primarily utilize cattle dung and wood for cooking and floor/wall washing. As a result, a nominal amount of 5% cattle manure is considered for making biogas without interrupting their normal routine and utilization pattern. A biogas combustion engine connected generator is envisioned for generating energy. The needed biogas is 0.75 m^3/kWh ('Biogas', a Ministry of New and Renewable Energy (MNRE) publication), with 21 m^3 (5% of 420 m^3 available (see Table 1). The electricity generation would be 28 kWh (21/0.75) with the stated specification. This is a nominal value for power generation because actual power output is contingent on biogas availability. The amount of biogas produced is determined by a number of factors that change from season to season. As a result, electricity generation is anticipated to fluctuate between 25 and 30 kWh throughout the year. The sensitivity variables of solar and hydro resources, as well as the cost of solar and hydro, are computed using the biogas scaled average of 0.5 tones/day (as per the previous calculation). Table 8 summarizes the sensitivity variables for the other systems.

5.2 Payback Period

It is the time (years) it takes for the cumulative income to equal the value of the initial investment and calculated by comparing the proposed and existing system configurations. Pay back period is shown by the intersection of two lines (base case system and lowest cost system) formulated in Equation (14).

$$Payback\ period = \frac{Initial\ Investment}{Savings\ per\ Year} \tag{14}$$

Table 10 Total energy generation from RES

RES	Operation Per Day	Generation (kWh/day)	Generation (kWh/yr)
60kW PV	5 hrs	300	99000
7.5kW Hydro	24 hrs	180	44100
3kW Biogas	8 to 10/day	27	9855
Annual Generation		507	152955

in this study, the payback period is calculated for two scenario's:

- Without Subsidy
- With Subsidy provided by Government [27]

For rural or remote areas, MNRE offers subsidies for the installation of RES, Solar PV 30%, Biogas Plant 10%, and Hydro Power 17%. Using the available data, sizing, equipment cost break-up, energy cost, monthly power generation from various sources of energy, payback period, and etc, are determined for the given two conditions.

5.3 Break-up Cost of MG Components (Without Subsidy)

The break-up of the components' cost of MG without subsidy is given in Table 9.

For maintenance cost, Rs 15/hour is applied with 8 hours of operation per day according to MNRE. The energy generated from renewable sources in a year is 152955 kWh as summarized in Table 10. The annual cost of this energy, if procured from the utility power grid at a rate of Rs. 6.25 per unit (the tariff of Jharkhand Urja Vitran Nigam Limited (JUVNL) in February 2021), would be Rs. 955968.75. The cost per unit comes out to be Rs. 5.32 as compared to Rs. 6.25 without the use of RES. This is a 14.88% savings per unit cost.

5.4 Cost of Components of MG System (With Subsidy)

The optimal component specifications, based on various system configurations, are obtained with a focus on minimizing the cost of energy (COE). The best configurations were obtained to give a minimum COE of Rs. 4.92/kWh (with subsidy). It is a 21.28 % reduction in per unit cost of energy. The configuration obtained also has a 63.1% share in total power supplied to the villages as summarized in Table 11.

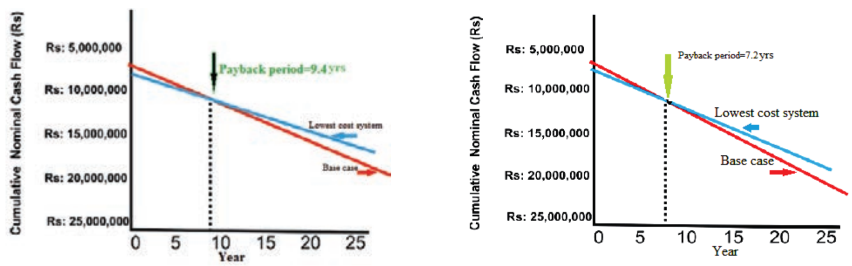
A comparison is presented in Figure 12 between the system configuration with and without subsidy. The capital cost with subsidy reduced investment

Table 11 Cost of components of MG system (with subsidy)

Components	Capital Cost (Rs.)	O&M (Rs./Year)	Subsidy
7.5 kW MHP	6225000	25000/year	17%
60 kW solar PV	1260000	4000/year	30%
3 kW Biogas	40500	43800/year	10%
45.3 kW Converter	237771	500/year	30%
Total	7763271	73300/year	

Table 12 Comparison of financial results and payback period without and with a subsidy

Status	PV (kW)	Biogas (kW)	Hydro (kW)	Conver (kW)	COE (Rs/kWh)	Cap Cost (Lakh.Rs)	RE Sharing (%)	Payback Period (yrs)
Without Subsidy	60.0	3.00	7.5	45.3	5.32	96.8	69.1	9.4
With subsidy	60.0	3.00	7.5	45.3	4.92	77.6	63.1	7.2



(a) Without Subsidy (b) With Subsidy

Figure 9 Payback Period for developed MG without and with subsidy.

costs from Rs. 96.8 Lakh to Rs. 77.6 Lakh whereas the COE declined from Rs. 5.32/unit to Rs. 4.92/unit. Similarly, the payback period with subsidy was reduced from 9.4 years to 7.2 years. The load demand varies continuously as shown by the load curves drawn on an hourly basis. The optimum generation from RE resources in a year is computed as 69.1% without subsidy and 63.1% with subsidy. At any point in time, the shortfall in energy will be drawn from the utility grid whereas excess generated power will be transmitted to the utility grid through a MG.

Conclusion

The objective of the research is to explore possibilities to make use of rural agriculture and bio-waste and other RES to develop a cost-effective and reliable MG-based energy system. This would serve as a step towards self-reliance in energy for the rural regions. The developed system would meet the major electricity demand of the cluster of three villages, namely Baheya, Karmadhippa, and Ulatu in Jharkhand, India. The local renewable energy resources, viz. solar, cattle dung, and hydropower are available in the cluster of villages and their power potential is estimated. The present tariff of the utility grid is Rs. 6.25 per unit, which can be reduced by 21.28 % with the installation of the proposed system. The return on investment analyzed for the renewable generation system is found to be 7.2 yrs, which categorizes it as a medium-term investment. To list some more benefits of the system: (i) It would provide local employment to the residents of the villages (ii) it improves overall renewable (environment-friendly) generation capacity of the grid (iii) reduces the loading of the transmission system, (iv) reduces transmission losses and (v) increases the reliability of the power system. As a future scope of the current study, load scheduling, energy storage, and energy trading aspects of the MG can be studied for the proposed system.

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