Sizing and Cost Analysis for Integrated Renewable Energy System in a Study Area

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Abstract

The renewable energy sources such as micro hydro, biomass, wind, solar photovoltaics can provide clean and sustainable electricity, as a result, many of sources are already proving cost-competitive contributing about 2% of the total electricity supply of the country. However, one of the issues limiting their greater penetration is done to its intermittent and seasonal availability for energy production. The availability of renewable power depends upon the resources potential and size of the system. The sizing for integrated renewable energy systems (IRES) depends on the uses of the system (load on the system) and the tariffs available from the local utility. In this paper, the sizing and cost analysis of MHP, biomass, wind and SPV system has been under taken.

Key words

Renewable Energy; Sizing; Costing; Modelling; Rural Area

1. INTRODUCTION

The increasing consumption of conventional fuels coupled with environmental degradation has led to the development of eco-friendly renewable energy sources. The development of remote rural areas could not take place even after more than 50 yrs independence, as the grid could not be extended due to its high cost, scattered nature of the area & low load factor. In recent years, the considerable R & D has been initiated to energize such areas through renewable energy sources, which are the best candidate for supplying the energy in decentralized mode. Depending upon the topography of the area, energy resources potential available, and type of energy needs/demand & socio-economic status of remote areas, the energy models can be developed and optimized in order to suit the needs of the area. Apart from meeting the energy needs using energy resources in individualistic manner, the demand can be best met using combination of the resources in integrative manner in cost effective & sustainable manner. The present study confines to electrical energy needs only. The paper reports the features of study area, sizing and cost analysis for models, development of Integrated Renewable Energy System (IRES) design models for the remote area.

2. FEATURES OF STUDY AREA

In India, Uttaranchal was created as new state in the year 2000 and consists of 13 districts, out of which Tehri Garhwal has been selected as the district and Jaunpur as block of the study area as it comprises of major hilly and the fertile area under forest, which is shown in Figure1. The total numbers of villages are 259 with 202 electrified and 57 un-electrified among these 12 un-electrified villages considered as study area. The study area has a total area of 485 sq. km. and total population 50636.

3. MICRO HYDROPOWER (MHP)

A large MHP potential still remains untapped in hilly streams, river rivulets and canal falls in India and therefore offers a promising source of energy, which could be exploited beneficially with short gestation period and least capital investment for the power generation and with ability to sustain the growth of industrial and rural development.

A. Sizing of Micro Hydro Power Plants

The total capacity and available energy from MHP is given in Table I. The total capacity based on resources of MHP is 59 kW and its energy is 393341 kWh/yr. The capital cost of micro hydropower system is Rs. 75000/kW and operation and maintenance cost is 2% of its capital cost. Thus, the total cost of MHP is Rs.75000 plus Rs. 1500 i.e. Rs. 76500/kW.

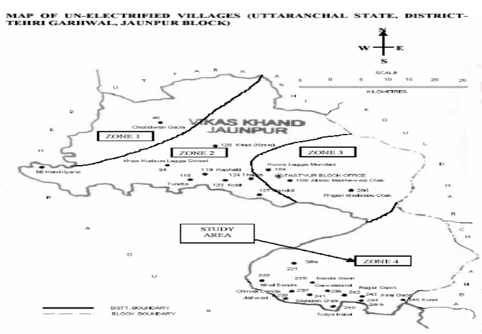

Figure 1: Features of the Study Area

4. BIOMASS ENERGY SYSTEM (BES)

Biomass gasification is a process of partial combustion, in which, solid biomass usually in the form of pieces of wood or agricultural residue is converted into a combustible producer gas. The gasifier consists of feed preparation, gasifier reactor, cleaning and cooling system, internal combustion engine/alternators & switchgear for energy distribution.

B. Sizing of Biomass Gasifiers

The Table II shows the standard sizes of gasifier systems available in the country and also applicable for the study area. The required biomass gasifier system capacities and their costs are given in Table III. The total cost of all size of the gasifier systems has been calculated as Rs. 15,81,000. The table shows that depending upon the availability of biomass in villages of the study area the biomass gasifier engine systems are required as 1 system of 5 kW, 7 of 10 kW and 1 of 50 kW rating. Specific fuel consumption is about 0.1 kg diesel fuel and 1 kg of biomass per kWh of energy generation [1]. The capital cost of biomass gasifier system is about Rs. 10,000/kW and operation and maintenance cost is 2% of its capital cost. Thus, the total cost of biomass gasifier engine system is about Rs. 10,200/kW.

TABLE I: Size & Cost of Micro Hydro Power of Study Area

SL. No.	Village No.	Head (H) (m)	Discharge (Q) (m^3/sec)	No. of Months in a year (Discharge is available) (Time)	Micro Hydro Power (P) (kW) P = 6.5 Q H	Micro Hydro Energy (E) (kWh/yr) E=P*Time	Capital Cost (Rs.)	O & M Cost (2%) (Rs.)	Total Cost of the system (Rs.)
1	V1	3.75	0.125	4	3	8784	225000	4500	229500
2	V2	NA	NA	NA	NA	NA	NA	NA	NA
3	V3	NA	NA	NA	NA	NA	NA	NA	NA
4	V4	NA	NA	NA	NA	NA	NA	NA	NA
5	V5	4.50	0.20	1	6	4464	450000	9000	459000
6	V6	NA	NA	NA	NA	NA	NA	NA	NA
7	V7	NA	NA	NA	NA	NA	NA	NA	NA
8	V8	4.125	0.20	12	5.5	48180	412500	8250	420750
9	V9	3.75	0.2125	12	5	43800	375000	7500	382500
		3.00	0.2125	12	4	35040	300000	6000	306000
		3.75	0.2125	12	5	43800	375000	7500	382500
		4.50	0.2125	12	6.5	56940	487500	9750	497250
		3.75	0.2125	12	5	43800	375000	7500	382500
10	V10	NA	NA	NA	NA	NA	NA	NA	NA
11	V11	3.75	0.125	12	3	26280	225000	4500	229500
12	V12	3.75	0.2125	7	5	25704	375000	7500	382500
		4.125	0.2125	7	6	30845	450000	9000	459000
		3.75	0.2125	7	5	25704	375000	7500	382500
TOTAL					59	393341	44,25,000	88,500	45,13,500

NA=Not Available

TABLE II: Size of Gasifiers

Category	Size (kW)	Annual Biomass Requirements (MT/yr)	Applications
Small Size	Up to 10	5.5 - 10	In rural areas, especially for providing thrashers, straw choppers, etc and also for domestic purposes.
Medium Size	10 - 50	10 - 425	In sawmills, carpentry workshops, mechanical fabrication shops as well as rice mills.
Large Size	50 and above	425 and above as for requirement	In rural as well as urban industries, these are need in small scale industries like dairy, oil mills, mineral processing, brick manufacturing, ceramics and pottery industries etc.

Source: [2]

TABLE III: Size & cost of biomass gasifier in the study area for electricity

SL. No.	Villages No.	Biomass Availability (Kg/yr)	Biomass Energy Available (kWh/yr)	Size of Gasifier (kW) × No. of Gasifier	Capital Cost (Rs.)	O & M Cost (2%) (Rs.)	Total Cost (Rs.)
1	V1	2595	2595	5 × 1	50,000	1,000	51,000
2	V2	0	0				
3	V3	300	300				
4	V4	98	98				
5	V5	470	470				
6	V6	465	465				
7	V7	0	0				
8	V8	19170	19170	10 × 2	200000	4000	204000
9	V9	496450	496450	50 × 1	800000	16000	816000
10	V10	1550	1550	10 × 4	400000	8000	408000
11	V11	40900	40900				
12	V12	13200	13200	10 × 1	100000	2000	102000
TOTAL		575198	575198	125 × 9	15,50,000	31,000	15,81,000

5. WIND ENERGY SYSTEM (WES)

Winds are caused because of two factors: (a) the absorption of solar energy on the earth's surface and in the atmosphere, and (b) the rotation of earth about its axis and its motion around the sun. Because of these factors, alternate heating and cooling cycles occur, differences in pressure are created, and the air is caused to move. Wind energy is thus an indirect manifestation of solar energy. The advantages of using wind energy are that its potential as a source of power is reasonably good and that its capture produces no pollution.

C. Sizing of Wind Energy System

Several wind turbine generators have been installed throughout the world. Unit ratings of wind-turbine generators cover a wide range from 0.5 kW to 14 kW. The classification of wind turbine systems is given in Table IV.

D. Sizing Calculation based on Study Area

Wind is a non-uniform, intermittent, erratic form of energy. Wind speeds in the range of 4 to 30 m/s are considered as useful. Average speed (10 m/s) is considered to be suitable for proper generation. Important parameters of wind are: (i) Velocity of wind (V), m/s and (ii) Power in wind (Pw), watt. Wind Power can be calculated as [4]:

$$P_W = \frac{1}{2}\ \rho\ \frac{\pi}{4}\ D^2\ V^3 \text{ Watts} \qquad (1)$$

Where P_W = Available wind power, ρ =Density of air, kg/m^3 (ρ = 1. 225 kg/m^3) and D = Circular of Diameter in horizontal axis aero turbine, m and A $=\frac{\pi}{4}D^2$ (sq. m.) (The amount of air passing in unit time, through an Area A, with velocity V is AV)

TABLE IV: Classification of Wind Turbine System

Category	Size (kW)	Applications
Very small	0.5 to 1	Domestic use like Radio, T.V., Fan etc
Small	1 to 15	Electricity, Small-scale Industries, Pumping water
Medium	15 to 200	Electricity, Small-scale Industries like Grinding flour
Large	250 to 1000	Electricity for Industries
Very large	1000 to 6000	Electricity for Industries

Source: [3]

The mean monthly wind speed data obtained from a nearby meteorological station are given in Table V. The Table VI shows the size of wind energy systems. In order to determine the unit cost of the system, a wind energy conversion system of 3 m rotor diameter of three-blade propeller type wind turbine having power coefficient as 0.45 has been considered. Using equation (1), about 300 W of power has been determined for an average wind speed of 5.5 m/s. Ten number of such systems has been considered for the study area with a total energy potential of 3600 kWh/year, considering 1200 hours operation in a year.

The capital cost of WES is Rs. 45000 - 70000/kW and operation and maintenance cost is 2% of its capital cost. Thus, the total cost of WES is Rs 71400/kW. Therefore, the total cost of installed capacity of 3 kW is calculated as Rs.214200/-. The system requirement is given in

Table VI, which shows that 10 machine of 300W each rating at a cost of Rs. 2,14,200/-.

TABLE V: Wind speed data available in the study area

Months	Mean Monthly Wind Speed (V) (m/sec)
January	5.44
February	5.51
March	6.10
April	6.37
May	6.28
June	5.01
July	3.55
August	2.99
September	4.29
October	5.34
November	5.57
December	5.81
Annual Average	5.19

Note - Wind Speed is Available only about 6 hrs per day
Source: [5]

TABLE VI: Size & Cost of wind energy system in the study area

SL. No.	Capacity of WES (kW)	Cost of WES (Rs./kW)	O&M Cost (2%) (Rs./kW)	Total Cost (Rs.)
1	300 × 10	70000	1400	214200

6. SOLAR PHOTOVOLTAIC (SPV)

There are several technical options and probably the most feasible one for the immediate future is the use of solar (photovoltaic) cell. Solar photovoltaic route facilitates direct conversion of sunlight into electricity. Electricity can be generated by photovoltaic effect using solar cells. By joining large numbers of these cells together (modules and arrays), significant amount of power can be generated whenever the sun shines.

E. Sizing of SPV Systems

The purpose of SPV system sizing is to calculate the number of solar modules and batteries needed to reliably meet the load of a given area throughout the year. Sizing of a PV system should be done carefully because over sizing has a very detrimental effect on the price of the generated power, while under sizing reduces the reliability of energy supply. Success of such a system depends upon the balancing of maximum reliability and minimum cost. The sizing of a system requires knowledge of the solar radiation data at the site, the load profile, and supply of continuity.

As discussed earlier, a SPV system consists of a PV array, storage battery and electronic interface. The correct selections of PV array and battery are vitally important. In order to size the SPV array for power, the array size can be calculated on the basis of load demand of the area. Under the present study, a stand- alone SPV system of 1000 W capacity plant has been considered to evaluate the unit cost of energy. Assuming that sunshine will be available for 6 hours per day and 300 days in a year, a energy potential of 1800 kWh per year has been considered to be available from SPV system.

The capital cost of SPV is Rs. 277500 - 327750/kW and operation and maintenance cost is 1% of its capital cost. Thus, the total cost of SPV is Rs.327750 plus Rs. 3277.5 i.e. Rs 331028/kW. Therefore, the total cost of installed capacity i.e. 1 kW is Rs. 331028, which is given in Table VII.

TABLE VII: Size & Cost of SPV in the Study Area

SL. No.	Capacity of SPV (kW)	Cost of SPV (Rs./kW)	O&M Cost (1%) (Rs./kW)	Total cost (Rs.)
1	1	327750	3277.50	331028

TABLE VIII: Total Cost of Renewable Energy Systems for Electricity Production

SL. No.	Renewable Energy Systems	Capacity (kW)	Total System Cost (Rs. in Lakhs)
1	MHP	59	45.14
2	BES	125	15.81
3	WES	3	2.14
4	SPV	1	3.31
TOTAL		188	66.40

The Table VIII shows the grand total a cost of renewable energy systems (electricity system) is Rs. 66.40 Lakhs.

7. DEVELOPMENT OF COST FUNCTION

F. Economical Analysis

Renewable energy systems are, in general, characterized by high capital costs, low Operation and Maintenance (O&M) costs, and zero fuels cost except biomass. The unit cost of energy generated by a non-burning fuel renewable energy system is obtained by considering the capital recovery cost and operation and maintenance cost. It has been computed using the following expression [6]:

$$C = \left[\frac{r(1+r)^n}{(1+r)^n - 1}\right]\left[\frac{P}{87.6k}\right] + \left[O \,\&\, M\right] \quad (2)$$

Where C is Cost of Energy, n is Amortization period (in years), O & M is Operation and

Maintenance cost, P is Capital cost, r is Fixed annual interest and k, Annual capacity factor, is

$$\frac{\text{Energy generated in kWh / year}}{(\text{System rating in kW})(8760\,\text{h / year})}$$

In case of biomass gasification, the cost of biomass and Diesel fuel is to be added as (0.3413 f/n) to the equation (2) and can be written as:

$$C = \left[\frac{r(1+r)^n}{(1+r)^n - 1}\right]\left[\frac{P}{87.6k}\right] + \left[O\,\&\,M\right] + (0.3413\, f/\eta) \quad (3)$$

Where f is Fuel cost in Rs. per million Btu at the generation site, and η is Overall efficiency of the plant

Procedure to estimate the unit is based on system reliability concepts, which assumes that there is no escalation in O&M costs during the amortization period and that there is no general inflation. O & M cost has been considered as 2% of the capital cost of the systems. Various cost operating parameters considered to evaluate the unit cost of energy are given in Table IX.

TABLE IX: Parameters considered for cost estimation

SL. No.	Parameters	Resources			
		MHP	BES	WES	SPV
1.	Energy generation (kWh/yr)	236005	203525	3600	1800
2.	System rating (kW)	59	45	3	1
3.	System operating hours (hrs/year)	4380	4600	1200	1800
4.	Amortizati on period (Year)	25	12	20	30
5.	Capital cost (Rs./kW)	85000	20000	7000 0	3300 00
6.	O & M cost (%)	2	2	2	1
7.	Annual interest (%)	11	11	11	11
8.	Fuel cost (Rs./kWh)	---	3.00	---	---
9	Unit Cost (Rs./kWh)	2.53	3.68	7.18	20.50

8. CONCLUSIONS

The capacity & cost of the renewable energy system has been given in Table IX. The table indicates that the total capacity of the renewable energy system is 108, out of which MHP (59), BES (45), WES (3) and SPV (1) kW for electricity only in the 12 villages of the study area. The cost of energy of the renewable energy system including distribution line consists of as follows from lower to higher- MHP (2.53), BES (3.68), WES (7.18) & SPV (20.50) Rs./kWh. Therefore, these costs of energy (unit cost) of renewable energy systems will be helpful for the integration of energy systems. After integration of the renewable systems, the unit cost of the systems up to the load will be reduced, systems becomes reliable and supply to the consumers will be eco-friendly. The integration of the renewable energy systems may be recommended using different optimization techniques such as linear programming, quadratic programming, multi-objective programming etc.

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10. REFERENCES

[1] Dasappa, S., Paul, P. J., Mukunda, H.S., Ranjan, N.K.S., Sridhar, G. and Sridhar, H.V. (2004), “Biomass gasification technology – a route to meet energy needs”, CURRENT SCIENCE, Vol. 87, No. 7, pp. 908-916.

[2] Rai, G. D. (1996), “Non-conventional Energy sources”, Khanna Publishers, 2B, Nath market, Nai sarak, Delhi, pp. 904 - 905.

[3] Rao, S. and Parulekar, B.B. (2000)," Energy Technology: Non-conventional, Renewable and Conventional", Third Revised and Updated Edition, Khanna Publishers, pp. 13-14, 25-28, 976-977 & 989-993.

[4] Abbasi, S.A. and Abbasi, N. (2001), “Renewable Energy Sources and Their Environmental Impact”, Prentice-Hall of India Private Ltd, New Delhi, p.38 & 74.

[5] Wind Energy Resource (WER) (2001), Survey in India–VI, Published by CENTRE FOR WIND ENERGY TECHNOLOGY, R-8, North Main Road, Annanagar West Extension, Chennai – 600 101.

[6] Ramakumar, R., Butler, N.G., Rodriguez, A.P. and Venkata, S.S. (1993), “Economic Aspects of Advanced Energy Technologies”, Proceeding of the IEEE Vol. 81, Issue No. 3, pp. 318-332.