Optimal Utilisation of Renewable Energy Sources in a Remote Area

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Abstract- The paper presents the study carried out for energy planning for remote area in order to meet out the demand by considering the optimal applications of renewable energy sources. The resources considered viz. Solar, Biomass, Wind and Small Hydropower and energy were computed based on assumed data. On this basis, the demand of the area has been considered as lighting, cooking, heating, shaft motive power and irrigation for agriculture. Models for various demands have been developed. The minimum optimum unit cost have been computed and compared

Keywords- Energy powered devices, Integrated Renewable Energy Systems, Minimum Optimum Cost, Optimal Utilisation

I. INTRODUCTION

Since the beginning of 20 century, there has been tremendous growth in population coupled with the increased consumption of energy in order to satisfy the daily needs of mankind. The energy needs especially that of rural communities are best fulfilled through the integrated renewable energy systems (IRES) in an appropriate & cost effective manner. Main advantages of IRES are that there is an increase in agriculture output due to availability of energy & fertiliser, timely availability of energy & other input commodities to the villages, to generate employment opportunities in villages, thus, also helps in improving the lifestyle & checks the migration of masses to the cities.

Several approaches have been proposed in the literature to design IRES. These include linear programming [6, 10] and Goal programming [3], probabilistic approach involving loss of power supply probability [1], and Trades off methods [4], and knowledge based approach [8]. Shekhar Sinha and Kandpal [11] have developed a framework for evaluating the relative economies of some of the common lighting technologies and this is then incorporated into a linear programming framework to obtain the least cost option for satisfying the lighting energy demand of a village subject to various constraints in the context of rural areas. Similarly, a linear programming micro model for determining an optimal mix of technologies for domestic cooking and irrigators sector has been developed for the rural areas of India. Ramakumar, et. al. [5] has used a knowledge-based approach to design IRES utilizing two or more renewable energy resources and end-use technologies to supply a variety of energy needs, often in a stand-alone mode. Knowledge -based design approach that minimizes the total capital cost at a pre-selected reliability level has been presented [7]. The procedure included some resource-need matching based on the resources. The design procedure has been coded into a computer program IRES-kB. Ramakumar and Hughes [9] have discussed some of the technical, economic and socio-economic aspects of the application of renewable (solar) energy sources for rural development in resource- poor population-rich developing countries.

Various authors have widely used optimisation as a tool and in particular, the linear programming approach has been adopted. Most attempts to date, however, have one or more of the following drawbacks. The models and methodologies are not flexible and/or general in nature, restricting them for particular technologies and/or end-uses. Limited attempt has been made to capture the specific nature of the performance and/or conventional technologies incorporating diverse possible technological options. Optimal mix of technology choices have been evaluated either restricted to financial analysis or to economic analysis rather than evaluating them from both perspectives for specific technologies.

II. PROPOSED STRATEGY FOR INTEGRATED RENEWABLE ENERGY GENERATION

As two approaches i.e. cascaded and tandem approaches have been proposed under the present study. In the cascaded approach, the dilute solar radiation is concentrated first for use in a heat engine to generate electricity.

The heat engine/generator units can be located at the focal points of an array of parabolic dishes or the outputs from several dishes can be thermally collected to feed one centrally located heat engine driving a generator. The medium-grade heat rejected by the heat engine is used in an absorption cooler system for refrigeration and low-grade heat rejected by the cooler system is used in applications such as water heating, space heating, and for maintaining the temperature of a biogas plant to optimize gas production.[2] Electricity generated by photovoltaic device and wind electric conversion system can be integrated at the electrical end and low-grade thermal energy obtained from other solar devices can be blended at the lower end of the cascaded energy chain.

In the tandem approach, several manifestations of solar energy are utilized either by converting all of them into one form (typically electrical with battery storage) or a few forms with energy storage for distribution to consumers, or by simply integrating the benefits at the user’s end. The versatility of biogas as a fuel and the inherent massive energy
storage possible with community-scale biogas plants suggest the integration of radiation and wind energy first, to be supplemented with biogas (biomass) as necessary and appropriate.

Solar radiation and wind energy can be integrated in many different ways – in the form of potential energy, low-grade thermal energy, or electrochemical energy, to mention only a few.

III. DEVELOPMENT OF COST FUNCTIONS FOR VARIOUS RESOURCES

The effective cost per unit of energy for each of the proposed resource – device combinations (variables) is an important factor in the optimisation model. The main objective is to optimize (i.e. maximize/minimize) an objective function subject to a set of constraints. This has been done using Linear Programming approach here. The cost function governs the optimal mix in such a manner that resources with lesser cost function share the greater proportion of the total energy demand in an attempt to optimize (minimize) the objective function.[12]

A. MODEL FOR LIGHTING

In a remote area, the demand for lighting needs will vary with the two seasons. In the summer season, the longer duration of the day implies that the effective number of hours for which illumination is needed will be less. On the other hand, during the winter season, the shorter days necessitate more illumination hours resulting in inflated effective demand of lighting energy [12]. The total demand of lighting energy has been estimated based on the assumed data. The data has been obtained from an assumed survey carried out in the village based on the representative sample data.

Solar photovoltaic (SPV) system

Based on the potential availability of SPV energy at the site, the SPV system constraint may be expressed as:

\[
\frac{SPV}{\eta_{LI}} \leq P \times S_h \times N \times \alpha \times N_m
\]  

Where,
P is the installed capacity of the SPV power plant depending on the financial availability of the implementing authority. 
S_h is the number of sun hours per day 
N is the number of effective sun days per month in the zone 
\(\alpha\) is the actual radiation coefficient that is a measure of the ratio of the actual insolation in the zone to the standard peak irradiance
\(N_m\) is the number of months per season for which radiation potential is estimated 
\(\eta_{LI}\) is the efficiency of connected electrical devices

Based on assumed values of the above-defined parameters, the supply constraint equations for both summer and winter can be expressed as:

\[
\frac{SPV}{0.9} \leq 2437.5 \text{ kWh} \quad (1)
\]

\[
\frac{SPV}{0.9} \leq 2537.5 \text{ kWh} \quad (2)
\]

Small hydro power (SHP) system

The supply constraint model equation developed for the summer and winter model, may therefore be expressed as:

\[
\frac{SHP}{0.9} \leq 56862 \text{ kWh} \quad (3)
\]

Biogas energy system

The supply constraint model equation developed for the purpose, may therefore be expressed as:

\[
\frac{Biogas}{0.7} \leq 507370 \text{ kWh} \quad (4)
\]

Wind energy

The maximum wind velocity for the remote area has been found to be 6.0 km/h, which is considered insufficient for giving any usable energy.

Development of Final Models (Lighting)

Summer Model

The final model can be formulated as

Minimise Objective Function

\[
\text{Cost } C_L = 10.09 \text{ SPV} + 1.29 \text{ SHP} + 1.96 \text{ Biogas}
\]

Subject to

i. \(SPV + SHP + Biogas = 286450.56 \text{ kWh}\)

ii. \(\frac{SPV}{0.9} \leq 2437.5 \text{ kWh}\)

iii. \(\frac{SPV}{0.9} \leq 56862 \text{ kWh}\)

iv. \(\frac{Biogas}{0.7} \leq 507370 \text{ kWh}\)

v. \(\text{SPV, SHP, Biogas } \geq 0\)

Winter Model

Minimise objective function

\[
\text{Cost } C_L = 10.09 \text{ SPV} + 1.27 \text{ SHP} + 1.96 \text{ Biogas}
\]

Subject to

i. \(SPV + SHP + Biogas = 326450.56 \text{ kWh}\)

ii. \(\frac{SPV}{0.9} \leq 2037.5 \text{ kWh}\)

iii. \(\frac{SHP}{0.9} \leq 56862 \text{ kWh}\)

iv. \(\frac{Biogas}{0.7} \leq 507370 \text{ kWh}\)

v. \(\text{SPV, SHP, Biogas } \geq 0\)
B. MODEL FOR COOKING

In model for cooking, the energy demand for the cooking needs in the assumed remote area will by and large remain the same for the two seasons. An exercise similar to that of the lighting demand has been carried out for the estimation of the cooking demand of the remote area.

Development of Final Models (Cooking)

Summer model

The final model equations can be formulated as:

Minimise objective function cost

\[ C_1 = 1.27 \text{ SHP} + 0.862 \text{ FW} + 0.60 \text{ Biogas} + 0.417 \text{ Solar cooker} \]

Subject to

(i) SHP + FW + Biogas + Solar cooker = 295954.23 kWh
(ii) \( \text{SHP} \leq 58077 \text{ kWh} \)
(iii) \( \text{FW} \leq 1067175 \text{ kWh} \)
(iv) \( \text{Biogas} \leq 92746.927 \text{ kWh} \)
(v) \( \text{Solar cooker} \leq 5250 \text{ kWh} \)
(vi) SHP, FW, Biogas, Solar Cooker \geq 0

Winter model

Minimise objective function equation

\[ C_1 = 1.27 \text{ SHP} + 0.862 \text{ FW} \]

Subject to

(i) SHP + FW = 185954.23 kWh
(ii) \( \text{SHP} \leq 58077 \text{ kWh} \)
(iii) \( \text{FW} \leq 1067175 \text{ kWh} \)
(iv) SHP, FW \geq 0

C. MODEL FOR SHAFT MOTIVE POWER

Development of Final Models (Shaft Motive Power)

Minimise objective function cost

\[ C_1 = 1.27 \text{ SHP} + 10.09 \text{ SPV} + 1.96 \text{ Biogas} \]

Subject to

(i) SHP + SPV + Biogas = 185764.94 kWh
(ii) \( \text{SHP} \leq 30577 \text{ kWh} \)
(iii) \( \text{SPV} \leq 2955265 \text{ kWh} \)
(iv) \( \text{Biogas} \leq 67440.56 \text{ kWh} \)
(v) SHP, SPV, Biogas \geq 0

D. MODELS FOR HEATING ENERGY

Development of Final Models (heating energy):

The final model equations can be formulated as

Minimise objective function cost

\[ C_1 = 1.27 \text{ SHP} + 0.862 \text{ FW} + 1.96 \text{ Biogas} + 1.94 \text{ Prod} \]

Subject to

(i) SHP + FW + Biogas + Prod = 295954.24 kWh
(ii) \( \text{SHP} \leq 30577 \text{ kWh} \)
(iii) \( \text{FP} \leq 82746.047 \text{ kWh} \)
(iv) \( \text{Biogas} \leq 92756.8 \text{ kWh} \)
(v) \( \text{FW} \leq 1067175 \text{ kWh} \)
(vi) SHP, FW, Prod, Biogas \geq 0

E. MODEL FOR IRRIGATION/AGRICULTURE PURPOSE:

Development of Final Models

The final model equations has been developed as

Minimise objective function cost

\[ C_1 = 1.27 \text{ SHP} + 10.09 \text{ SPV} + 1.96 \text{ Biogas} + 1.94 \text{ Prod} \]

Subject to

(i) SHP + SPV + Biogas + Prod = 295954.23 kWh
(ii) \( \text{SHP} \leq 30577 \text{ kWh} \)
(iii) \( \text{SPV} \leq 2955265 \text{ kWh} \)
(iv) \( \text{Prod} \leq 82746.927 \text{ kWh} \)
(v) \( \text{Biogas} \leq 67440.56 \text{ kWh} \)
(vi) SHP, SPV, Prod, Biogas \geq 0

IV. RESULTS AND DISCUSSIONS

A. LIGHTING MODELS

Case 1: Summer model

Table I gives the optimisation results for the model. Here, varying effects of EPDF on the lighting load shares of SHP, SPV and Biogas can be seen. The reduction of EPDF from 1.00 to 0.25 does not produce any appreciable change in the contribution of SPV plant and the demand is met by corresponding increase in the contribution of biogas plant whereby the constraint of its maximum availability is met continuously. The system gives the unit cost of energy equivalent to Rs 1.84.
Case II: Winter Model

has not been taken as the contributing factor keeping the minimum cost of the plant at the minimum. Reduction in SHP plant capacity can be tolerated without any appreciable rise in the unit cost.

B. COOKING MODEL

Case I: Summer Model

Table III gives the optimisation results for the model. In this model, EPDF has been defined in terms of the energy delivery of the biogas. The stability of the model system will be governed by that resource which is most likely to influence the overall objective function. It can be seen that for values of EPDF of 1.00 and 0.75, the contribution of the SHP plant is nil. SHP plant contributes for values of 0.50 and 0.25. The average unit cost of energy from this system works out to be Rs. 0.84.

Case II: Winter Model

Table IV gives the optimisation results for the model. Here Fuel wood (FW) has been considered for varying EPDF. As can be seen, for values of EPDF of 1.00 and 0.75, SHP plant does not contribute for the calculation of optimum cost. For value of 0.50, substantial contribution of SHP plant is observed changing the unit cost to Rs. 0.92. Also, as seen the system does not have any feasible solution for EPDF of 0.25.

D. MODEL FOR HEATING ENERGY

The optimisation results for this model is as given in the Table V. Here, EPDF has been defined in terms of the Producer gas. Here, it is seen that as the constraint on the availability of the producer gas increases, the load is being shared by the biogas resource as well. At an EPDF of 1.00, the contribution of biogas is nil. As the EPDF decreases to 0.25, i.e., as the availability of Producer gas is restricted, demand is being fulfilled by the contribution of biogas only. It can be seen that there is no effect on the contribution of SHP and FW, i.e., there contribution remain essentially constant, without any appreciable change in the unit cost which works out to be Rs 0.946.

E. MODEL FOR SHAFT MOTIVE POWER

The optimisation results obtained for this model is as given in Table VI. Here the EPDF has been defined in terms of Biogas. As the availability of Biogas is restricted, the demand is met through SPV only. There is no change in the contribution of SHP, which remains constant at 18701 kWh. Also, as can be seen unit cost (in Rs) increases from 7.70 to 8.82, a increase of 14.63%.

F. MODEL FOR IRRIGATION

Table VII gives the optimisation results for this model. EPDF has been defined in terms of SPV, as it is the predominant resource contributing to the demand. The unit cost comes out to be an average of Rs 8.098. This is obvious from the fact that in the first iteration the optimal value of SPV comes out to be 224328.4 which is much less than the

Similarly, Table II gives the optimisation results for this model. From a comparison of the results of the summer and winter models of lighting, it can be seen that the SPV plant availability of this resource. Hence no variation in the unit cost is observed as the EPDF varies.

V. CONCLUSIONS

Thus we conclude with this observation that Lighting model for summer and winter show similar trends and so do Cooking (summer & winter) and also heating and Irrigation models. Maximum variation has been observed for the Shaft Motive power where the unit cost of energy is affected widely as system parameter is changed.

VI. Acknowledgment

The first author gratefully acknowledges the “Ministry of Non Conventional Energy Sources, India” for the financial support receiving under the Senior Research Fellowship scheme, because of which the work reported in the paper was possible.

VII. REFERENCES