Off-Grid Biomass Gasification Based Rural Electrification in Lieu of Grid Extension

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ABSTRACT: This study is focused on a model towards choosing between off-grid biomass gasifier system and conventional grid extension for rural village electrification. The approach is to formulate a relation between biomass gasifier system capacity and the economical distance limit (EDL) from the existing grid point, based on life cycle cost analysis (LCC). EDL is the distance at which LCC of energy for both the options will match. The life cycle cost of energy is calculated for various capacity of biomass gasifier system at various operation hours and grid availability. The LCC of energy varies between $ 0.12/kWh to $ 0.11/kWh for gasifier system capacity of 10 kW to 120 kW for 6 hour of daily operation. The EDL for a 25 kW biomass gasifier system is 10.4 km considering 6 hours of daily grid availability and operation. This analysis shows that for villages having low load demand situated comparatively away from the existing grid line, the gasification based systems are cost competitive than photovoltaic systems or even grid extension. CO_2 emissions mitigation benefit from the biomass based system is also included in the analysis.
Keywords: Biomass gasification systems, decentralized power generation, grid extension, economic analysis

1 INTRODUCTION

Rural electrification is a vital development programme for socio-economic situation improvement of the rural areas of a country. It facilitates economic development through employment generation and as an input for productive uses in agriculture and rural industries. It also improved the quality of life of the people by means of providing light in homes, shops, community centers [1]. At present, 80% of the total villages in India has access to grid electricity; leaving a balance of approximately 125,000 villages still waiting to be connected to the grid [2]. Out of this, 25,000 are difficult ones, where extension of grid is neither possible nor economical [2]. The rural electrification programmes within the different states of India are widely diverse.

Eight states (Andhra Pradesh, Goa, Haryana, Maharashtra, Kerala, Punjab, Tamil Nadu and Nagaland) have achieved 100% village electrification, which constitutes only 18% of the villages of the country. States with 80% or more households yet to be electrified (Bihar, Jharkand, Assam, Orissa, Uttar Pradesh, and West Bengal) constitute 43% of country's total rural households. However, the 80% of the total villages in the country has achieved electrification while, only 43.5% of the rural households have access to electricity [3].

The investment required for extending the grid depends on the distance of the load centre from the existing grid centre and the average demand of the village. The cost of delivered electricity depends on load factor, transmission and distribution losses and cost of the electricity generation. Hence, low load factors, long distribution lines, low load densities and associated high transmission and distribution losses make many of the rural electrification programme economically unattractive. Even electrification wherever done, is under criticism since in many cases; the consumers do not have access to power. Moreover, the quality of power is very poor and availability is also uncertain. Alternatively the decentralized use of renewable energy resources is proving to be a viable and more efficient for rural electrification. Such rural electrification programmes have brought substantial improvement in the quality of life of rural people, especially women and children. The development of modern technologies like biomass gasification systems has kindled its possible use in the form of distributed, off-grid electricity to end use needs.

1.1 Biomass Gasification based Rural Electrification

Biomass gasification based rural electrification is becoming popular as it has edge over other renewable due to cost effectiveness, support grid quality electricity and high plant load factor. Biomass gasification systems have been used for rural electrification in India with partial success [4-7]. Mukhopadhyay presented the socio economic and environmental impact of the biomass gasification based power plant in Chottomollakhali islands of Sunderbans [5]. The finding of this study indicates that the power plant has increased the economic activities and quality of life of the peoples. Dasappa et al addresses distributed biomass based power generation system that has developed at Indian Institute of Science, Bangalore [8]. This study deals in detail the field experience on using open-top downdraft systems coupled with gas engines. Nouni et al presented techno-economic evaluation of biomass gasifier based projects for decentralized power supply for remote locations in India [6]. Siemons tried to evaluate the potential of biomass based rural electrification in developing countries in terms of feasibility and suitability of the technology [9].

Abe et al examined the biomass gasification systems based on agricultural residues and woody biomass to provide power to the rural areas in Cambodia [10]. This study found that rice husks or cashew nut shells have high-energy potential along with tree farming or plantations for sustainable resources supply for biomass gasification system in the country. Buchholz and Silva investigates the potential of wood-based biomass gasification systems to provide affordable basic electricity services to rural Ugandan households [11].

This study also focused on developing business plans and provides a general framework to compare different options of electricity production across technologies and fuel sources especially for rural development.

Ravindranath et al has done a detailed study on the performance and impact of decentralized biomass gasifier based power generation system in an un-electrified village of Karnataka, India [12]. This was one of the pioneering successful biomass based power generation systems in India which operated over more than 14 years to meet all the electricity needs of the village. This work also presented an overview of technical, social, economic and management-related lessons learnt from this project.

Dasappa et al examined in details on operational experience of 100 kWe grid connected biomass gasification based project at Karnataka, India [7]. This Bio Energy for Rural India (BERI) project is a new kind of work, which connected a number of villages with decentralized gasification system connected to rural grid to augment the rural energy access. It is observed that the specific energy cost is lowest in the gas engine operation in compare with dual-fuel mode of operation. Mahapatra et al presented in details the various option for domestic lighting available for rural households and concludes that modern bio-energy systems at village levels is better option for providing good quality and reliable lighting in rural areas compared to traditional kerosene-based lighting [13]. Application specific criteria are required for widespread deployment of biomass gasifiers and also to meet the need of the end user.

The most significant benefit of decentralized energy sources is that it can be made available in remote areas, where conventional energy supply is not economically possible [1]. The minimum load requirements for a rural household includes power for domestic demands such as lighting in home, street lightings, fans, television and drinking water supply. Apart from this, small scale industries like dehulling machines, flour mills etc. are also required in the villages which are not accounted in the estimation of average load for households. In this present study the average connected load for each household is considered to be 0.50 kW. The detailed calculation for this estimation of the connected load is presented in Table I.

Table I: Estimation of average load for each household

Load	Number of units	Rating (watt)	Coverage fraction (1)	Load (watt)
Lighting	4	15	1	60
Street lighting	1	20	1	20
Fans	2	75	1	150
Television	1	100	1	100
Drinking water pump	1	3730	0.05	186.5
Total connected load				516.5

This study is focused on the modeling towards choosing between off-grid biomass gasifier based system and the conventional option of grid extension for remote village electrification. The approach is to formulate a relation between the biomass gasification system capacity and the economical distance limit (EDL) from the existing grid point based on life cycle cost analysis (LCC). The EDL is the distance where the LCC of energy of the biomass gasification system matched with the grid extension. Typical case studies on distributed biomass gasification based power generation systems are used for the analysis. Further the CO_2 emissions mitigation potential and associated benefits from the biomass energy systems with respect to grid extension are also included in the cost analysis.

2 BIOMASS GASIFICATION SYSTEM

Biomass gasification involves partial combustion of biomass under controlled air supply, leading to generation of producer gas constituting the combustible gases H_2 (20%), CO (20%) and CH_4 (1–2%). The energy value of producer gas is about 4.5-5.0 MJ/kg. The producer gas can be used as fuel for internal combustion engine for electrical applications. Typical off-grid biomass gasifier base system is shown in Fig. 1. The initial cost of the system is generally conceived to be high, however operation cost is low because the present gasifiers are coupled with gas engines in place of the dual fuel mode of operation used earlier and fuel is locally generated biomass, with no diesel consumption. The biomass gasification systems consists of fuel and ash handling system, reactor (gasification system), gas cooling and cleaning system and auxiliary systems like water-treatment plant. The clean and cooled gas feed into either diesel engine or a spark-ignited gas engine coupled to an alternator. The system design is based on the load demands of the households of a village or couple of villages. Along with the domestic load, gasifier can also plays a vital role for providing electricity to the small scale village industries. For this present study five different system capacities 10 kW, 25 kW, 50 kW, 70 kW and 120 kW are considered for different sizes (depends on number of households) of villages. The analysis has been done by considering the different operation hours of these systems. In case of biomass gasification systems, the increase in operation hours will increase the fuel requirements. However, increase in load demands does not require increasing the gasifier ratings; as the gasifier turndown ratio is quite high.

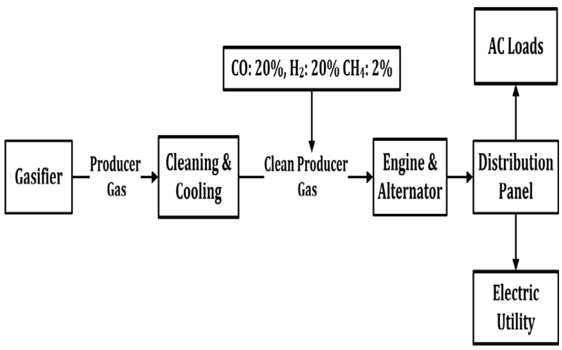

Figure 1 Off-grid biomass gasification base system

3 GRID CONNECTED SYSTEM

The power sector in India has made significant growth over the years. However, more than 100,000 villages still remain to be electrified. Again, it is important to note that the *'electrification'* was not based on the percentage of households has access to electricity, but merely extension of electricity lines to a particular area of a villages. Moreover, the rural electrification programme is not always economic and financial viable to the State. Hence, the quality of power or the availability of power is very poor. Most of the times, there will be no power, particularly in evening, when it need more for lighting in the households. So for economic and financial viability of rural electrification projects, expansion of productive use of electricity by promoting agro-based industrial activities is essential apart from uses for lighting or agricultural water pumping [14].

The most preferred method of providing electricity is installing centralized power plants either coal based or hydro and transports the electricity from the generation point to the load centre by existing transmission lines or laying new transmission lines [1]. Cost estimation for grid extension is obtained by aggregating (i) the cost of transmission lines of 11kV or 33kV or a combination of both depends on the load and (ii) the cost of 11kV/0.4kV substation. The large transmission losses (technical and non-technical like theft and pilferage), low load demand in the villages and grid expansion costs are the main disadvantages of these kinds of schemes. As the grid availability is poor in the rural areas, only three different grid availabilities (6, 8 and 12 hours) are considered for the analysis in this study.

4 ANALYSIS

The competitiveness of biomass gasification based power generation for rural electrification is assessed and compared with the conventional option of grid extension.

The cost of biomass gasification systems is determined for different capacity. At the same time, the cost incurred to extend the power lines from the available grid point to the village is also determined. The life cycle cost of energy ($/kWh) at the end point is used to compare these options. Biomass price is considered constant in its entire project duration and inflation and the salvage value are not considered for simplicity in calculations. All these calculations are made by using discount factor of 12%. The baseline year of all the costs reported in this study is 2009-2010. Table II provides the input parameters for the cost analysis. The low tension transmission distribution lines costs within the villages has been excluded, since it is the same in both the cases.

The LCC of energy is calculated by considering the capital cost, fuel cost for its entire project life, present worthy value of the operation and maintenance cost, component replacement cost etc and also the total carbon trading benefits in its entire project life. The LCC of energy for both the options are calculated by dividing the total life cycle cost of the system with the total energy output in its project life from the systems. The LCC value for different capacities of biomass gasification system is calculated by using the following relation.

$$LCC_{BG} = \frac{C_G + C_E + (C_F + C_O) \times P(d,n) + C_R \times P(d,n_1) - C_C \times P(d,n)}{L \times h \times n}$$

$$C_F = (S_C \times f_{con} \times h \times f_c)$$

$$C_O = (S_C \times h \times m_c)$$

$$C_C = (L \times h \times n \times C)$$

C_G *and* C_E are the capital costs for the gasifier systems and engine, L is the gasification system capacity, h is the annual operation hours, n and n_1 are the life of a specific components and the complete project, d is the discount rate, P is the present worth factor. C_F is the annual fuel cost, C_O is the annual maintenance cost, C_R is the component replacement cost and C_C is the annual carbon benefit. S_C is the gasifier ratings (kg), f_{con} is the fuel consumption per kW, f_c is the unit fuel cost, m_c is the maintenance cost of the systems ($/kWh) and C is the carbon emission benefit ($/kWh).

Table II: Input parameters for cost calculations

Biomass gasification systems	
Biomass consumption per kW (kg/hr)	1.4
Life of the gasifier systems (yr)	15
Life of engine (yr)	7.5
Annual maintenance cost ($/kW)	0.033
Fuel cost ($/kg)	0.033
Grid extension	
Life of the projects (yr)	20
T & D loss (%)	20
Electricity cost ($/kWh)	0.056
Annual maintenance cost (% of capital cost)	1
Carbon trading	
Carbon emission factor (kg/kWh) (2)	0.81
Carbon trading ($/tones)	14

The grid extension cost depends on the distance of the village/load centre from the existing grid, cost of distribution transformer and operation and maintenance cost of the grid line along with the transformer. The cost of delivered electricity at the village or load centre is depends on the cost of unit power generation (electricity cost at exiting grid point), transmission and distribution losses, load demand and grid availability. So, the life cycle cost of grid extension depends on life cycle cost of electricity generation at village load centre, capital cost for grid extension depending on the distance of the village load centre from the existing grid point (grid line cost), cost of distribution transformer and operation and maintenance costs. The expression for calculation of LCC of energy (Rs/kWh) for grid extension can be written as;

$$LCC_{GE} = \frac{LCC_{gen} + LCC_{grid} \times X}{L \times h \times n}$$

Where, $LCC_{gen} = t_{gen} \times L \times h \times (\frac{1}{1-\delta_{t\&d}}) \times P$

$$LCC_{grid} = C_{grid} + C_t + (C_{grid} + C_t) \times \beta \times P$$

$$P = \frac{d \times (1+d)^n - 1}{d \times (1+d)^n}$$

LCC_{GE}, LCC_{gen} and LCC_{grid} are the life cycle cost for grid extension, electricity generation and grid line cost, X is the distance from the village load centre to the existing grid point. L is the load demand, h is the annual operation hours, d is the discount rate and n is the life of the project. t_{gen} is the electricity generation cost, $\delta_{t\&d}$ is the transmissions and distribution losses, P is the present worthy factor, C_{grid} is the grid line cost, C_t is the distribution transformer cost, β is the fraction of capital cost for operation and maintenance cost of the grid.

The economic distance limit (EDL) is calculated by considering the distance at which the life cycle cost of biomass energy systems and the grid extension will match. The following expression is used for this calculation.

$$\frac{LCC_{grid} \times EDL + LCC_{gen}}{L \times h \times n} - LCC_{BG} = 0$$

EDLs values are calculated for different capacity of biomass gasification systems and for various operation hours of the systems at various grid availabilities.

5 RESULTS AND DISCUSSIONS

The life cycle cost of energy from biomass gasification system are calculated for the different system capacity and presented in Table III. Three different operation hours (24, 12, and 6 hours) are considered in this analysis. The life cycle cost is varying from $ 0.06 /kWh to $ 0.12/kWh for 24 hours to 6 hours of operation respectively for a system capacity of 25 kW. The energy generation per day increases with the increase in operation hours, however the life cycle cost increase due to only the fuel cost and operation and maintenance cost for longer operations hours. Hence, the LCC of energy decreases with the increase in operation hours. Again, there is a slight decrease in LCC value, as the system capacity increases from 10 kW to 120 kW. This is due to the slight reduction in systems cost with the increase in capacity. Biomass gasification systems are suitable, when there are other small scale industrial loads like flour mills, rice husking units or agro-based industries that get connected apart from the domestic loads. These loads actually increases the operation hours of the systems and consequently decreases the LCC of energy. This enhanced operation hours also enhance the sustainability of the systems, as this capability becomes very important for village economic development.

Fig. 2 represents the life cycle cost for grid extension for 6 hours grid availability for various loads. The LCC of grid extension has two components; the LCC of generation and LCC of grid lines for a particular distance.

The grid line cost is the vital parameter than the life cycle cost of the energy generation. It can be observed from the Fig. 2, that as the distance from the village load center to existing grid point increases, the grid extension cost increases. At low load, the LCC of energy for grid extension is much higher in compare to a larger load at any particular distance. It means, as the load increases, the LCC cost of energy decreases at a particular distance due to the higher energy generation. The analysis for grid availability of 8 hours and 12 hours has also been done and follows the similar trends.

Table III: LCC of energy from biomass gasifier systems

System daily operation (hr)	LCC ($/kWh)				
	Load (kW)				
	10	25	50	70	120
24	0.061	0.060	0.060	0.059	0.054
12	0.082	0.081	0.079	0.078	0.072
6	0.123	0.122	0.118	0.116	0.109

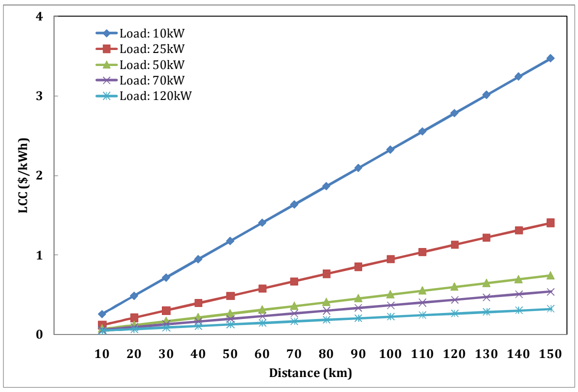

Figure 2: LCC of energy for grid extension

The critical distance of a load center from the existing grid point above which the economic performance of grid extension will be matching with the biomass gasification systems, depicted as economic distance limit (EDL) has been calculated for different system capacity. Fig. 3 represents the EDL values for different gasification systems capacity at various operation hours. The grid availability kept constant to 6 hours by considering the present rural electrification scenario. The EDL value varies from 4.2 km to 41.6 km for the system capacities of 10 kW to 120 kW respectively for 6 hours of daily operation and grid availability. The EDL values for a 25 kW capacity system with operation hours of 6, 12 and 24 hours are 10.4 km, 5.9 km and 3.7 km respectively for 6 hours grid availability. It is observed from the Fig. 3, as the operation hours increases, the EDL values are coming down. However, it is observed as the grid availability increases, the EDL for the systems also increased for a particular operation hours. The EDL for 25kW systems with 12 hours of operation comes to 11.9 km at grid availability of 12 hours, though it is not very much realistic in present rural electrification scenario. Hence, it can be conclude, for a 25kW biomass gasification system will be economical attractive, if the village is approximately 12 km (considering 12 hours grid availability) far away from the existing grid point.

A comparative analysis on EDL for biomass gasification systems and photovoltaic systems has been done. It has been found that the EDL value for photovoltaic system is 36 km for a 25 kW system capacity with grid availability of 6 hours. Whereas, for biomass systems for same capacity, operation hour and grid availability it is 10.4 km. Hence, it can be conclude that the biomass gasification systems are more economical competitive in compare to photovoltaic systems.

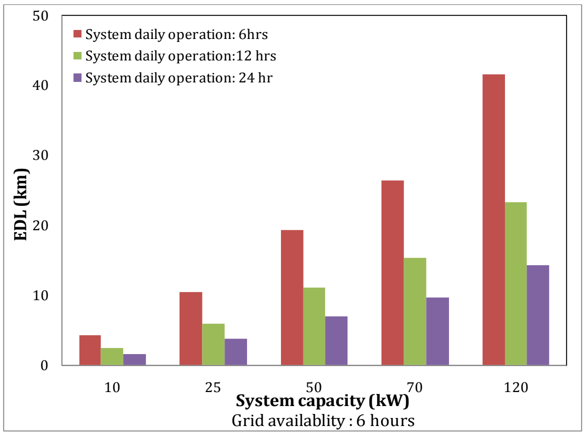

Figure 3: EDL for biomass gasification systems

Table IV: EDL sensitivity with fuel cost and grid availability

Variation of base parameter (%) (3)	EDL(km)	
	Fuel cost	Grid availability
-50	9.0	10.4
-25	9.7	15.7
0	10.4	20.9
25	11.2	26.1
50	11.9	31.3
75	12.6	36.5
100	13.3	41.8

The LCC of energy from biomass gasification systems is dependent on biomass fuel cost and the LCC of energy from grid extension is on the availability of electricity in grid. Hence, it is important to check the sensitivity of the EDL on the relative change in biomass fuel cost or in grid availability. It has been tried to find out the EDL at various relative change in base price of biomass and base grid availability. Table IV represents the EDL sensitivity with biomass cost and grid availability for a 25 kW system with 6 hours of daily operation. It can be observed from the Table IV, as the biomass price increases, the EDL also increases proportionally. Similarly, with the relative change in grid availability, the EDL has increased. The biomass gasification systems will be in village itself and the required biomass will be generated from the dedicated agro-forestry or from agro-residue, so the change in biomass price will be minimal. In the present rural electrification scenario, the quality is very poor and the availability is also very uncertain. So, the positive relative change in grid availability may not be possible even in future. Hence, in present situation, the EDL value may not much differ with the biomass price or grid availability.

6 CONCLUSIONS

Access to good quality and reliable electricity to all is a great challenge in contemporary India. Despite many efforts by the government, still there are numbers of households does not get the benefit of electricity. The LCC of energy varies between $ 0.12/kWh to $ 0.11/kWh for gasifier system capacity of 10 kW to 120 kW for 6 hour of daily operation. The EDL for a 25 kW biomass gasifier system is 10.4 km considering 6 hours of daily grid availability and operation. This study observed that decentralized power generation by biomass gasification systems can be cost competitive, in terms of life cycle cost analysis, for remote villages with comparatively low load demand. Though the generation cost of grid electricity is low, the effective cost per unit electricity becomes higher for grid extension than that of biomass energy base systems when the distance of the village load centre from the existing grid is large, due to high transmission & distribution losses and grid extension cost.

This study concludes that the biomass gasification base systems are economic competitive than the photovoltaic base systems or even to grid extension for far away villages. It is also important to mention that the most significant social benefit of the use of decentralized energy sources available in village itself; provide good quality and reliable power supply. The reliable power supply actually can enhance education, business, security, women empowerment through small entrepreneurship etc. for an overall economic development of the village. Biomass energy base systems also have the CO_2 emission reduction potential in place of conventional coal based power generation systems.

7 NOTES

(1) Coverage fraction 1 means each household use the load independently, factor 0.05 means the water pump load will be share between 20 households
(2) This emission factor, defined in the context of the clean development mechanism, gives equal weight to the average emissions factor of all operating power plants and of recently built power plants. The grid emission factor (combined margin for 2009-2010) in India is 0.81 $kgCO_2$ / kWh [15].
(3) The base parameter: fuel cost is $ 0.033/kg and grid availability is 12 hours.

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