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Techno Economic Analysis of Hybrid Solar PV and Biomass System for Rural Electrification

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Abstract - *The emerging potential of renewable based electricity generation systems, diversity of storage and various loads are interconnected through the microgrid structure. Techno-economic study to design and develop a biomass based hybrid renewable energy systems for the microgrid application for a typical rural site is described in this paper. Analysis shows that the grid connected per unit tariff is minimum Rs 5.50 whereas the per unit tariff for hybrid energy system is Rs. 2.935 per kWh. An analysis was also carried out for various factors such as tariff rates, capital cost of solar-PV and biomass. In this paper, the renewable hybrid power generation which is suitable for Kewatali Bazar, a village situated in Uttar Pradesh has been discussed. All the details regarding the load of the village have been collected and the amount of power to be generated by solar PV-bio hybrid system has been calculated accordingly.*

Key Words: *Rural electrification, Biomass plant, Solar PV plant, Economic considerations, Carbon credits, load details.*

1.INTRODUCTION

The provision of reliable electricity supply systems is among the primary needs for the socio-economic development of a country. Energy has to be conserved in a in most efficient manner as it is vital for the progress of a nation. The use of Renewable Energy technology has been steadily increasing so as to meet demand. Most importantly, energy should be produced in the most environment friendly manner by using all varieties of fuels and it should also be efficiently conserved. However, there are some drawbacks associated with renewable energy systems such as poor reliability and lean nature. Biomass is the biological material from living, or recently living organisms. As an energy source, biomass can either be used directly, or converted into other energy products such as biofuel. Biomass (fuelwood, crop residues and cattle dung) accounts for about 40% of India's primary energy use [1]. This world of deteriorating amount of non-renewable resources, the relevance of a biomass gasifier is immense [2]. Power generation from biomass has become a complement to conventional sources of energy due to its contribution to the reduction of greenhouse effect [2]. Biomass ranks fourth as an energy source and, in developing countries. Gasification converts biomass in to a combustible gas mixture of carbon monoxide, hydrogen and methane [2]. It must be noted that gasification is cheaper as well as having considerable efficiency. Hybrid plants will become an increasingly attractive option as the cost of solar thermal falls and feedstock, fossil fuel and land prices continue to rise [3]. The Block Diagram of Biomass Gasifier plant is shown in figure 1.

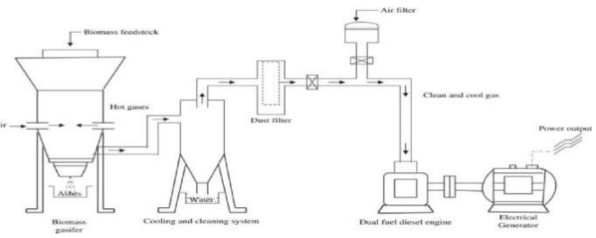


Fig 1: Block Diagram of Biomass Gasifier plant

Over 200 million people, live in rural areas far away from the grid [4]. The installation and distribution costs are considerably higher for remote areas [5]. Moreover, there is greater transmission line losses and poor supply reliability [6] [7]. Like several other developing countries, India is characterized by severe energy deficit. In most of the remote and non-electrified sites, extension of utility grid lines experiences a number of problems such as high capital investment, high lead time, low load factor, poor voltage regulation and frequent power supply interruptions. The provision of electricity through renewable energy-based decentralized generation options can be financially more attractive as compared to extending the grid [4]. There is growing interest in harnessing renewable energy sources since they are available in abundance, pollution free and inexhaustible. Presently, standalone solar photovoltaic systems and biomass systems have been promoted around the globe on a comparatively larger scale. Nixon J D et.al [8] in their study of hybrid solar – biomass power plant concluded that in comparison to biomass-only, hybrid operation saves up to 29% biomass and land. They further concluded that hybrid plants will become an increasingly attractive option as the cost of solar thermal falls and feedstock, fossil fuel and land prices continue to raise The Block diagram of a typical Solar- Biomass hybrid energy system is shown in figure-2.

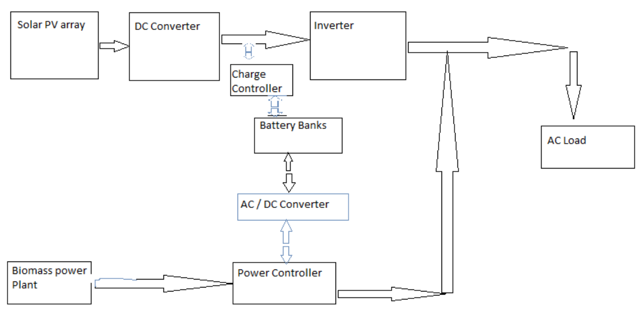


Fig: 2 Block diagram of Solar Biomass hybrid energy system

Community hybrid power systems can range in size from small household systems (100 Wh/day) to systems supplying a whole area (10's MWh/day) [9]. Gianni Celli. Et.al [10] presented in their paper about Optimal Location of Biogas and Biomass generation plants. In this paper they presented the use of optimization algorithm for biomass availability, transportation, power facilities along with territory related constraints. Kumaravel S etal [11] conducted techno-economic study of biomass based hybrid renewable energy systems for the microgrid application operated in rural area. They concluded that the grid connected hybrid system requires additional capital cost of 8.79%. The complete load details of the village Kewatali Bazar, Gorakhpur district U.P, India was collected and accordingly amount of power to be generated by solar PV-biomass hybrid system is calculated in the paper.

2. DESIGN FOR SOLAR PV SYSTEM

Sun is the primary source of energy. It is renewable, inexhaustible and environmental friendly. India is blessed with large amount of sunshine all the year with an average sun power of 490W/m2/day [4]. Solar charged battery systems provide power supply for complete 24hours a day. PV cell are solar cells that convert sun energy directly into D.C electricity. Semiconductor materials are used to make this solar cell in PV module. The electricity generated from PV cell can be used to power a load or can be stored in a battery. PV systems generally can be much cheaper especially to remote areas.

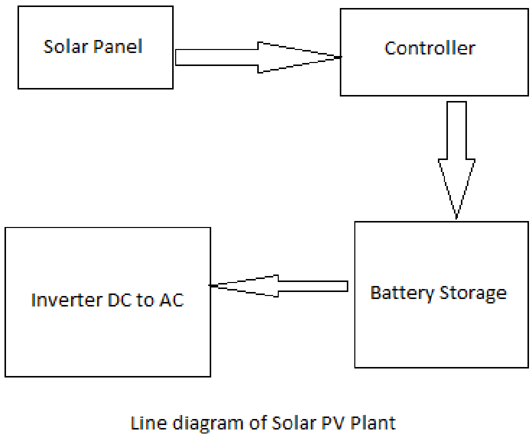


Fig 3: Solar PV plant

The major components are PV modules, dc to dc converter, battery and inverter. The capacity of these components can be determined by estimating the load to be supplied. The size of the battery bank required will depend on the storage required, the maximum discharge rate, and the minimum temperature at which the batteries will be used. For choosing a battery size, all these factors should be considered. Lead-acid batteries are the most common in P.V systems. **PV cells** are used to generate electrical energy by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

When light shines on a PV cell, it may be reflected, absorbed, or pass right through. But only the absorbed light generates electricity. The energy of the absorbed light is transferred to electrons in the atoms of the PV cell semiconductor material. With their newfound energy, these electrons escape from their normal positions in the atoms and become part of the electrical flow, or current, in an electrical circuit. A special electrical property of the PV cell—what is called a "built-in electric field"—provides the force, or voltage, needed to drive the current through an external load, such as a light bulb.

Storage battery: A **rechargeable battery**, **storage battery**, or **accumulator** is a type of electrical battery. It comprises one or more electrochemical cells, and is a type of energy accumulator. It is known as a **secondary cell** because its electrochemical reactions are electrically reversible. Rechargeable batteries come in many different shapes and sizes, ranging from button cells to megawatt systems connected to stabilize an electrical distribution network. Several different combinations of chemicals are commonly used, including: lead–acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer).

Rechargeable batteries have lower total cost of use and environmental impact than disposable batteries. Some rechargeable battery types are available in the same sizes as disposable types.

Charge controller, otherwise called as charge regulator, is the core of every solar system, and is required to monitor and control the flow of power into and out of the battery. It also regulates the power flow from solar panel to the battery to ensure that the battery is not overcharged. The charge controller must also ensure that the connected loads don't over-discharge the battery, thereby damaging it.

A **solar inverter** is used to convert the DC output of a solar panel into a utility frequency alternating current that can be fed into a grid. Battery backup inverters are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. Solar inverters are used for other purposes like maximum power point tracking and anti-islanding protection.

Electric load design Analysis for the system:

The storage capacity, S_c, of the battery can be obtained by (4 x Total energy to be stored per day) / (Battery

voltage x battery current).

Number of panels required, NP = Rating of solar PV plant / Rating of solar pv panel

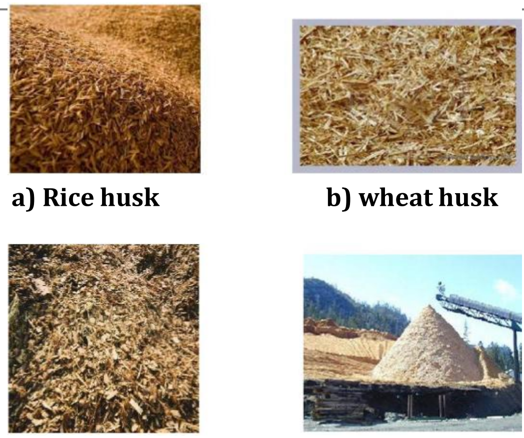
The charging controller can be designed using the following formula:

Controller current, $_{IC,}$ Total power to be stored per day / VB

The number of batteries required can be obtained by, NB , Total power to be stored / (VBx IB) where, VB, IB are the voltage and current rating of each battery.

3. INTRODUCTION TO DESIGN FOR BIOMASS SYSTEM:

Biomass is the most interesting and emerging option to supply future energy demands. Although not all biomass can be used to generate electricity, only small fraction of it can be utilized to produce substantial amount of energy.The percentage of different traditional uses were : Cow – dung 20.4%, jute stick 7.5%, rice husk 23.3%, baggase 3.2%, fiere wood 10.4 %, twigs and leaves 12.5% and other wastes 11.2% [5]. However, the energy efficiency of this technology is limited and the operating and investment costs are high, resulting in low financial returns. Some sources of biomass is shown in figure 4.



a) Rice husk **b) wheat husk**

c) Wood chips **d) Saw dust**

Fig 4: Biomass Crops

Biomass power plants have capacities typically ranging between 2-50 MWe [5]. Thermal conversion of biomass materials to higher calorific value and dense fuels is currently gaining increased international interest due to their renewable character and potential to reduce green house gas emissions [7]. The larger plants benefit from comparatively higher energy efficiencies (usually up to 22-23 %) but have to face the challenge of meeting a demand for large amounts of biomass, a resource characterized for its increasing scarcity, high cost and seasonality [5]. Biomass particles size ranges varies from 5 cm to few mm. The feedstock should preferably be free due to the heat needed to vaporize the water within the particle; however maximum moisture content up to 30% to 50% were mentioned [5]. Biomass gasification and pyrolysis plants typically require external electrical power for operation when the plants are optimized for fuel production [12].

4. METHODOLOGY:

(i) Study Location

Kewatali Bazar is a village in Uttar Pradesh, a number of parameters was used for the selection of the village.

- Different degree of economic development
- Population size not exceed 1500
- Income disparity between different group not too high
- Good public co-operation

A survey was done to find information on energy consumption, data was collected from all 196 houses in Kewatali Bazar the total animal dung collectable was also calculated.

Village Profile	Village	Kewatali Bazar
Block Pipraich		
District Gorakhpur		
Population	1236	
Average family size	06	
Number of household	206	
Livestock population	123	

Kewatali Bazar is endowed with land (0.20 ha/capita). The animal density is 0.6/capita as far as cooking fuel is concerned small quantity of kerosene is used with biomass.

Analysis:

Load Estimation:

Table1: Domestic load of the village

S.No.	Gadget	Number	Rating(W)	Total rating(W)	Duration(hrs)	Load(KWh)
1.	Compact	150	15	2250	8	18
2.	Fans	150	60	7200	8	72
3.	Water	08	1500	12000	4	48

Due to domestic loads units consumed per day is 138 units

Table2: Community load of the village

S.No.	Gadget	Number	Rating	Total rating	Duration	Load(KWh)
	T.V	1	300	300	8	2.4
	Computer	1	600	600	4	2.4
	Tube	5	55	275	8	2.2
	C.D player	1	100	100	8	0.8
	Fans	3	60	180	8	1.44

Energy Consumption of Village:

For community hall design the load consumed per day is 9.24 units. For street lighting we are using 26 Tube fluorescent lamps and these are operating 10 hrs per day, so these consume 14.3KWh per day. So the total units consumed per day are 162units.

5. Design Results:

(i) Design of PV Panel:

Total load = 15KWe

Period of operation or duration = 7 Hours

Then, Total Watt-Hour = 15×7= 105KWhr

The period of the solar panel exposed to the sun = 7 Hours (Averagely between 9am and 4pm)

Therefore solar array wattage = 15 KW

Hence solar panel of 15,000W will be needed for this design.

If solar panel of 150W is to be use the number of panels to arrange in parallel to achieve 15,000 Watt will be:

No. of panel= $10000W/150W$=100

This shows 100 of 150 Watt solar panel will be required for this design

(a) Charging Controllers:

For this design of 10KW solar power supply P=IV

Where,

I is the expected charging current and

V is the voltage of the battery and = 12 V

P is the power supply rating= 15KW

Normally 8 hours per day is the sunshine available hours, from solar PV array maximum units can generate is 15 X 7= 105 KWh, if solar PV array can generate 70% of its rated capacity then it can generate 73.5 KWh per day, in day time directly we are giving to the consumers from solar power plant, so minimum 24KWh directly we can distribute without storing it, remaining 50KWh is we have to store in the battery banks.

Hence I = P/V= 50000/12=4166*Amps.*

Since the value 5KA charging controller is needed to charge the battery banks.

(b) **Battery capacity:**

Watt-hour capacity = 50 kWh

To make the chosen battery to last long it is assumed that only a quarter ($^1/_4$) of the battery capacity will be made used of so that it will not be over discharged therefore hence the required batter capacity will be ---50,000 X 4 = 2,00 kWh

Now the choice of battery hour depends on A-H rating of the storage battery. For example, for 500Ah, 12V battery the number of batteries that will be needed is 2,00,000/(12 X 500)=34 batteries. Hence, for this design and to avoid too much weight and occupying unnecessary space, 34 batteries will be needed.

(c) **Inverter:**

Since the total load is 50KWh it is advisable to size the required inverter to be 10KW as designed for solar panel ratings. Hence 10KVA pure sign wave inverter is recommended in other to prolong the lifespan of the inverter.

Biomass power plant:

(a) Biomass resource availability:

In Kewatali Bazar the biomass availability is 0.30 kg/cap/day

Population of the village is 1236

The total biomass availability in the village is around 370 kg, from this we can generate the sufficient power, to satisfying the load requirement of Kewatali Bazar village.

(b) Plant rating:

Here we are installing the power plant is 6 KWe and we are connecting to the synchronous generator, so it will gives the rated voltage and frequency and gasifier can give the gas 12 hrs/day from this we can generate 72 units minimum per day, biomass plant is working at peak loads and solar is working at day time and solar power we are storing through batteries and one controller also we are placed so that it will control the power flow to the consumer load.

Economic Consideration:

Biomass Power Plant:

Table 3: Summary of Biomass Gasifier Plant

Plant capacity	8 kW
Cost of installation	Rs.4,00,000
Maintenance cost	Rs.10,000
No of consumers	206
Operation hours	12 hrs
Fuel efficiency	1.5 kg of crop residue/kWh
Cost of fuel	Rs. 0.25/kg
Operating period	20 years

Table 4: Operation cost per unit electricity:

Description	With grid	With gasifier system
Electricity	Rs.4.5/kW	Rs.0.37/kWh
Labour cost	Rs.0.45/k	Rs.0.25/kWh
Maintenance	Rs.0.07/k	Rs.0.25/kWh
Total	Rs.5.02/kWh	Rs.1.37/kWh

Table 5: Summary of Solar PV power plant

Plant capacity	15 kW
Cost of installation	Rs.2700000
Maintenance cost	27000
No of consumers	206
Operation hours	7 hrs
Operating period	20 years

Hybrid system cost:
Biomass:
Total installation cost of biomass = Rs 4,00,000
Maintenance cost of the biomass plant = 2.5 % of the installation cost
Total cost (installation and maintenance) of the plant = 4,00,000 + (0.025 X 4,00,000)
=Rs.4,10,000
Operating years = 20 years
Per day we can generate = 96 units
So, per unit cost in Rs. = 4,10,000/(20 X 96 X 365) = Rs 0.58.
Total cost per unit generation = Installation and maintenance costs + operation cost
= 0.58 + 1.37 = Rs 1.95
Solar:
Total installation cost = 180 X 15,000 = 2700000 (per watt installation cost is Rs.180)
Maintenance cost of the solar PV plant = 1 % of the installation cost
= 2700000+ (0.01 X 2700000)
= Rs.2727000
Operating years = 20 years.
Per day we can generate = 73.5 units.
Per unit cost = 2727000/ (20 X 365 X 73.5) = Rs 5.082.
Hybrid:
Per unit cost from hybrid system = (2400 X 1.95 + 1102.5 X 5.082)/(2400 + 1102.5)
= Rs 2.935
Through hybrid energy system, per unit generation and distribution cost is not beyond Rs3, whereas
grid connected per unit tariff is minimum Rs5.50.
So, through hybrid energy system, the cost of generation is also less as compared with the conventional energy.
Carbon Reduction Potential:
Co2 emission from biomass per unit generation = 6 g/kwh
Co2 emission from solar pv plant per unit generation = 68 g/kwh
Per day we can generate power from biomass = 96 X 365 = 35040 kWh
Per year we can generate the power from solar pv plant = 73.5 X 365 = 26,827.5 kwh
Carbon emission from solar pv plant per year = 26827.5 X 0.067 = 1824.25 kg = 1.825 tonnes/year = 1.825 carbon credits
Carbon emission from biomass plant per year = 35040 X 0.006 = 210.24 kg = 0.2102 tonnes/year= 0.2102 carbon credits
From total hybrid system, the carbon emitted per year = 1.825 + 0.2102 = 2.0352 tonnes/year
If the same energy is generated through conventional (coal), then carbon emitted per year= 1.5*(35040+26827.5) = 92.80 tonnes/year.
So by installing renewable hybrid system, the carbon emission reduction = 92.80 – 2.0352= 90.76 tonnes/year = 90.76 carbon credits.
Total money earned through carbon credits = 90.76* 30 = 2722.8 $ (USD) = Rs 1,82427 per year.

6. RESULT AND DISCUSSION:

In order to evaluate the unit cost of energy generation, a 15kw standalone solar photovoltaic system has been considered.` Assuming the sunshine hours of 6 hrs per day and 365 days of operation. Capital cost of solar pv is Rs 2727000 and the total cost of bio energy system is 4, 10,000. The total cost of installed capacity is therefore Rs 3137000 as shown in Table 3 and Table 5. After the above calculation, the unit cost of the solar – biomass hybrid energy system was found to be Rs 2.935. The capacity of the biomass plant used in the study is 8 kWe, this plant is also connected to the synchronous generator with rated voltage and frequency. Assuming that Gasifier produces the producer gas for 10-12 hrs/day, a minimum power of 96 KWh per day can be generated. The biomass plant will work at peak loads (for most of the time). Similarly, power can be generated by the solar plant at day time for 7 hrs (9 a.m to 4 p.m). At night time, load will be shifted to batteries or biomass system depending on the demand. So during clear sunny day the net power generated from solar plant is 73.5 kWhr.

VII. Conclusion:

Being far away from the main grid, some of the remote villages are still unelectrified. Due to the distance problem, losses increase and transmission line installation cost goes high. The renewable hybrid system with solar pv and the biomass which helps in overcoming all these problems have been discussed in this paper. It also calculates the load requirement of Kewatali Bazar village and estimates the energy requirement in order to satisfy this load. It can be concluded that solar and biomass hybrid system is a viable green technology source for rural electrification.

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