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Energy Management through Bio-gas Based Electricity Generation System during Load Shedding in Rural Areas

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Abstract

The scarcity of energy especially electrical energy is an acute problem and hinders the modern economic development of a country. Most of the time only a small percentage of peoples have access to use continuous electricity supply. But in this modern era, all types of arena like economies, households and companies have extensive demand for electricity which is due to industrialization, extensive urbanization, population growth, rising standard of living and modernization of the agricultural sector of a country. Electricity generation from bio-gas plant through cowdungs of a dairy firm can mitigate the electricity demand to some extends in rural areas, where biogas plant will act act as a backup supply especially during load shedding. This research paper proposed an electricity generation system from bio-gas, which can work as a secondary source of the electricity for all electrical appliances of a particular area in a cost effective manner.

Keywords: *Biogas, Digester, HRT, Renewable energy, Load shedding, Backup supply*

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1. Introduction

The electricity infrastructure plays an important role for the generation of employment and socio-economic growth in developing countries more than the developed ones. In Bangladesh like other developing countries, expansion of economic activities is interrupted due to underdeveloped electricity infrastructure and poor management system. Therefore, from the old days, Bangladesh is regarded as an electricity deficit country which has shown clear impact on its economic activities. This limitation is due to the inadequacy of supply, inefficient machines, poor quality of services and also huge government subsidies. As recorded on February 2017, Bangladesh has one National Grid having an installed capacity of 15,379 MW. Bangladesh's energy sector is booming day by day. Recently Bangladesh started construction work of Rooppur Nuclear Power Plant with capacity of 2.4 GW and is expected to go into operation in 2023 [1]. But it is considered that the per capita energy consumption in Bangladesh is low. Bangladesh has small reserves of oil and coal, but very large natural gas resources.

Hence, natural gas is the main source of electricity generation that causes the establishment of gas-based power plant in a large number. Commercial energy consumption is mostly natural gas (around 66%), followed by oil, hydropower and coal. But still the supply of electricity is inadequate to meet the present growing demand. As a result, frequent electrical power outages or load-shedding is done reduce the gap between the demand for electricity and available generation in Bangladesh. It has been estimated that the loss of annual industrial output due to frequent power outages in Bangladesh is approximately $1 billion per year. One of the major reasons of slow Gross Domestic Product (GDP) growth is power sector and the Government of Bangladesh (GOB) has recognised the power sector as a priority sector for increasing GDP growth. GOB has decided to build more power projects through public private partnership and private sector. In the Power System Master Plan (PSMP-2010) demand forecast was made based on 7 % GDP growth rate. To increase access and attain economic development, electricity development is required to be accelerated.

The desirable economic growth rate would be about 7% per year. Based upon this study the peak demand would be about 17,304 MW in FY2020 and 25,199 MW in 2025 [2].

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According to PSMP- 2010 Study year-wise peak demand forecast is depicted in Figure 1. As 2015 almost 92% urban population and 67% rural population have the access to the electricity for their source of light and in average 77.9% population have the access to the electricity in Bangladesh. It is one of the least per capita electricity consuming economies in the world with the per capita electricity consumption rate of 321 in 2014 which increased from 75.88 Kilowatt hour (kWh) in 1995 [3-4]. According to Bangladesh Power Sector Master Plan (PSMP), to attain 8% GDP (Gross Domestic Product), the electricity demand would be around 34,000MW by the year 2030. Bangladesh will require total US$18 billion investments in the power sector to balance this demand-supply gap. A number of incentives for the foreign investment in the power sector have been provided by the revised private sector power generation policy of Bangladesh. The government of Bangladesh (GOB) has adopted Power System Master Plan (PSMP) 2010 of Table 1 to provide access to quality electricity to all people at an affordable price as the basis for future projects to be undertaken in this sector [5-7].

Bio-gas is the by-product of anaerobic digestion of organic waste like cow-dung. It has been accepted to be a promising and practicable technology with a very reliable, successful and clean source of energy when proper management program is followed. Now-a-days, bio-gas plants are widely used for fulfilling the smale scale demand for electricity especially in rural areas. Also this technology can also be used as the back up power source for the rural areas under national grid during load-shedding [8-10]. It ensures the most reliable and uninterrupted power supply. This paper mainly represents the energy scenario, the present condition and utilization with the potential benefits, prospects and challenges of the bio-gas technology and energy management under the absence of national grid supply in Bangladesh. This paper also analyses the cost estimation for this bio-gas plant and its capability to work as an energy back-up system during power outages. This research concept of energy management through bio-gas plant will be able to overcome electricity shortage in recent days especially in rural areas to some extends.

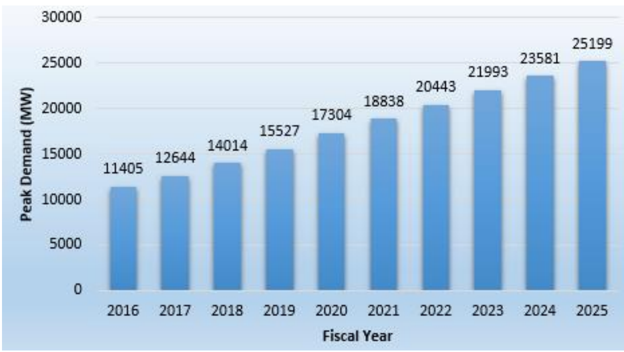

Figure 1. Year-wise Peak Electricity Demand Forecast

Table 1. Total Generation Plan from Different Sources by the Year 2030 [2]

Fuel Type	Capacity (MW)
Domestic Coal	9850
Imported Coal	7800
Natural Gas/ LNG	8956
Cross-Border Pow er	3500
Liquid Fuel	3428
Renew able Energy	2000
Hydro	500
Total	36034

2. System Flow Diagram

For the designed system cow-dung is the input of the electricity generation plant. Though, several farms can provide the waste for bio-gas generation in this system. Here a dairy farm having 80 cows are provided the necessary waste for the whole plant. The size of the digester depends on the total amount of loads of the system under consideration. Hence, the total loads of the system should be calculated before designing the plant. The output of the plant can be used to supply energy to a good number of consumers as a back-up source during the absence of national grid supply i.e. load shedding. The detail operation process of the electricity generation system from bio-gas is depicted in Figure 2.

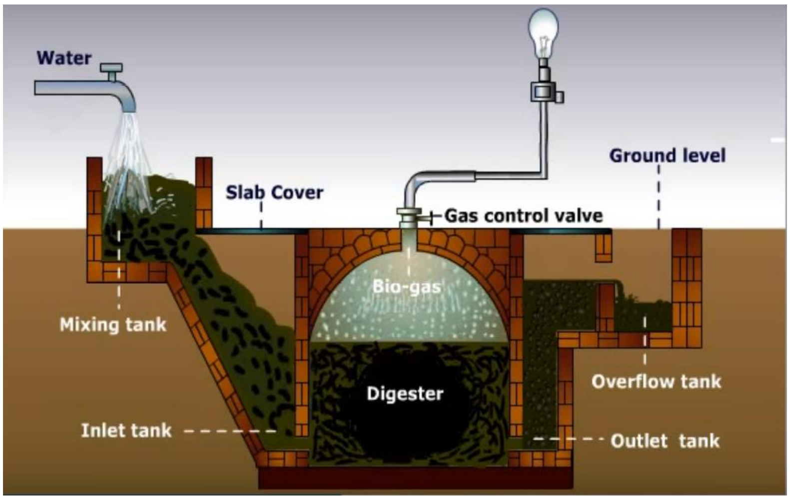

Figure 2. Flow Diagram of the Bio-gas System

3. System Load Forecasting

Load estimation is an essential part for the smooth operation and planning of an electrical utility house during design issue. It is required to take decisions on purchasing and generating electric power, load switching, and infrastructure development of the belongings. The size of the digester required for the designed plant is calculated as 2200 CFT. The load demand of the designed system by single consumer is shown in Table 2.

Table 2. Single Consumer's Daily Load Demand

Load Name	Rating (Watt)	Quantity	Power (Watt)
Energy Bulb	26	04	104
Tubelight (48")	32	01	32
Ceiling Fan (48")	75	01	75
Colour LED TV (24")	40	01	40
Total Consumed Power			251 Watt

4. Total Solid Estimation

The designed system will serve a particular village area just like a mini power plant for a number of houses under a particular union. In Figure 3 the system approximate design layout is depicted.

Now, the cow-dung required for the plant is provided by a dairy farm having 80 cows of average body weight 220 Kg each.

Let, System Temperature = $30^{o}C$

Hydraulic Retention Time (HRT) = 40 days [11].

Total calculated discharge from cows = (10×80) = 800 Kg/day

Total Solid (TS) Value of fresh discharge = (800×0.16) = 128 Kg/day

Now considering 8% concentration of TS,

Influent from 128 Kg solid = $\frac{100 \times 128}{8}$ = 1600 Kg/day

So, Total amount of influent, Q = 1600 Kg/day

Amount of water for the 8% concentration of TS = (1600 – 800) = 800 Kg/day

Figure 3. The Design Layout of the Bio-gas Plant

5. Parameter Estimation

5.1. Digester

As the digester is the main part of the system, cross-section of the digester is depicted in Figure 4. Where,
Volume of chamber (Gas Collecting) = V_c
Volume of chamber (Gas storage) = V_{gs}
Volume of fermentation chamber = V_f
Volume of hydraulic chamber = V_H
Volume of sludge layer = V_S

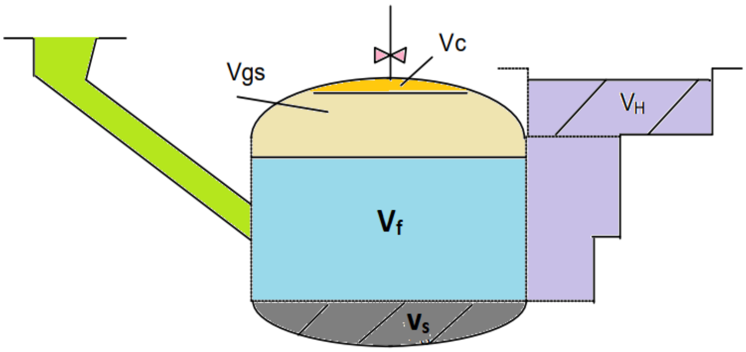

Figure 4. Cross Section of the Designed Digester

Total volume of digester $V = V_c + V_{gs} + V_f + V_s$
Now,
Working volume of the digester = $V_{gs} + V_f$ = Q.HRT = 64000 Kg = 64 $m^3 \approx$ 2200 CFT
This design requires some geometrical assumptions which are shown in Table 3.
From geometrical data analysis,

$$V_{gs} + V_f = 0.80\ V$$
$$\Rightarrow V = 80\ m^3$$

Now, Diameter $D = 1.3078\ V^{\frac{1}{3}} \approx 5.64$ meter

Again, Height $H = \frac{4 \times 0.3142 \times D^3}{3.14 \times D^2} \approx 22.56$ meter

Table 3. Geometrical Assumptions for Digester Design [11]

For Volume	For Geometrical Dimensions
V_c<5% V	D = 1.3078 × $V^{\frac{1}{3}}$
$V_s < 15\% V$	V_1 = 0.0827 D^3
V_{gs} + V_f=80% V	V_2 = 0.05011 D^3
V_{gs}= V_H	V_3 = 0.3142 D^3
	V_c = 0.05V
V_{gs}= 0.5(V_{gs}+V_f+V_s)K	R_1 = 0.725 D
where K = gas production rate per cubic meter volume per day. For Bangladesh K = 0.4 m^3/day	R_2 = 1.0625 D
	f_1 = D/5
	f_2 = D/8

Similarly, from assumption f_1=1.13m, f_2=0.71m, R_1=4.09m, R_2=6.0m, V_1=14.84m^3, V_2 =9.0m^3, V_3 =64.53m^3, V_c=0.05V = 4m^3. Final design of digester chamber is depicted in Figure 5.

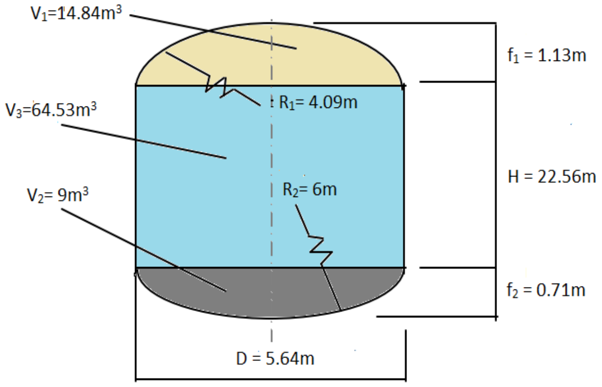

Figure 5. The Dimension of Digester Chamber [24]

4.2. Hydraulic Chamber

From assumption value,
V_{gs} = 50% of daily gas yield
= 0.5 × TS × gas production rate per Kg TS
= 17.92 m^3 ≈ 600 CFT

Now, $V_1 = \left[(V_c+V_{gs})-\frac{\{\pi D^2 H_1\}}{4}\right]$

$H_1 = 0.283$m

If water volume h = 1.8 m

$h = h_3 + f_1 + H_1$

$\Rightarrow h_3 = 0.387$ m

Again, $V_{gs} = V_H$

$\Rightarrow 17.92\ m^3 = 3.14 \times (D_H)^2 \times \frac{h_3}{4}$

D_H=7.68m

Final design of hydraulic chamber is depicted in Figure 6.

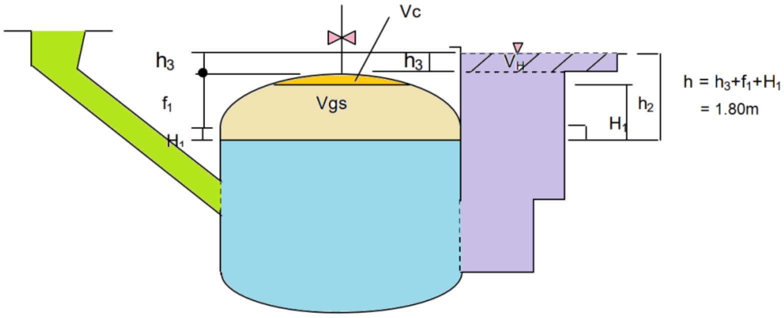

Figure 6. The Dimension of Hydraulic Chamber

5. System Operation

Overflow of floodwater into the digester chamber can break down it's operational capacity and hence it should be kept away from floodwater for efficient operation of the plant. Although a large part of Bangladesh experiences flood almost every year. Floodwater can collapse the gas production capacity of the plant. But it is extremely difficult work to prevent flood water in flood prone areas. To solve this problem it must be ensured that the design of the digester is such as to prevent digester from water. The main design factors of the system includes digester size, waste nature, waste availability, site selection, system demanded load and the generation capacity of the generator depicted in Figure 7-8. The digester is filled up with the required quantity of waste materials i.e. cow-dung after designing the system. For producing required amount of gas, the waste materials are kept air-tight inside the digester till the HRT period. At the end of HRT period, the pressure of gas inside the digester is sufficient enough to be used for both cooking purpose and running the generator.

Figure 7. Base Construction of Digester

Figure 8. Cow-dung Collection

Figure 9. Designed System Output

6. Produced Energy Estimation

For cow-dung, maximum gas production per kg = 0.05 m^3
Total produced gas by the system = 0.05 × Total cow-dung in kg = 40 m^3
As 1m^3 gas produces 19 Mega Joules energy (3.6 kWh = 1 joule)
Total energy generated by the plant = 211.11 kWh
Considering 25% energy loss as heat and other mechanical losses by electric generator hence net energy produced = 158.33 kWh.
So the system is capable of delivering uninterrupted energy to 430 (approx.) consumers for an hour with a maximum demand of 0.314 kWh.

7. System Installation Cost

Installation cost of the system is higher due to the cost of digester and electric gas generator. The total installation cost of the system is shown in Table 4.

Table 4. Cost of designed system

Name of the Item	Cost (USD)
Construction cost of Digester (2200 CFT)	2558.00
Construction cost of Hydraulic Chamber and Gas Collecting Chamber (600 CFT)	678.00
Purification Unit & Accessories	153.00
Gas Generator 250 kVA (Intraco)	6875.00
Electrical Wiring Equipment & Accessories	456.00
Miscellaneous Cost	426.00
System Cost	$ 12635.00
Total Cost (10% maintenance cost/year)	$ 13898.50

8. Cost Estimation of Per Unit Energy

Here, calculated load per day 251W, considering utilization hours 10 hr per day.

Energy Consumed per day (251 $\times$ 10 $\times$ 430) = 1079.3 kWh

Total energy supplied = (1079.3 $\times$ 365) = 393.9445 MWh/year

Per unit energy cost = $\frac{\$\ 13898.50}{393.9445 \times 10^3}$ = $ 0.0353 /kWh (i.e. 2.82 BDT)

Designed bio-gas plant, require very less maintenance for digester in its whole life time. Including the maintenance cost of generator, the resulting per unit cost is only 2.82 BDT which is lower than the present determined unit price (i.e. $ 0.08475 /kWh ≈ 6.78 BDT) of electricity by the authority of Bangladesh Rural Electrification Board [12].

9. Scope of the System

The above designed system can be used as the back-up system in absence of National Grid during load shedding. In case of failure of National Grid during blackout, this system will be highly reliable and efficient to solve the problem of electricity. The implemented system can produce net 158.33KWh (25% is considered as system loss) of electric energy which is sufficient for supplying uninterrupted power supply to approximately 430 houses. The system can also supply necessary gas for cooking purposes. Slurry of the system can be used as fertilizer for land by the fermers. Thus the designed system is very efficient and is capable of fulfilling the energy requirement with renewable energy source. Beside these, the extra power can be sold to the National Grid. The designed system is capable of providing electricity with a rate of $ 0.0353/kWh where, country's normal rate set by Bangladesh Rural Electrification Board is $ 0.08475/kWh. Hence, this system is also very cost effective and is able to mitigate the electricity crisis and also capable of acting as a back-up source.

10. Conclusion

Electriciy generation through Bio-gas technology can be considered as a partial but one of the most significant cost effective backup solution to energy scarcity. Though adoption of this does not only end with the construction of a larger plant, but also it requires some proper planning with respect to creation of social and economic acceptability apart from technological diffusion. In recent times availability of backup electricity supply is very much encouraged by the authority where, only a portion of all electrical appliances will have the access to derive its benefit accordingly to ensure sustainable development of a country.

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