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DESIGN AND IMPLEMENTATION OF A HYBRID ENERGY NEUTRAL HOME SYSTEM FOR BANGLADESH

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ABSTRACT
Bangladesh is passing a crucial time in power sector due to power shortage. The electricity production is mainly dependent on non-renewable energy resources in Bangladesh. For that reason, the reserve of natural resources or non-renewable energy sources such as: fossil fuels, oil, natural gas etc. are diminishing day by day. So this is the time to search such a system where the residential areas of Bangladesh become Energy Neutral. This paper demonstrates such a hybrid Energy Neutral Home (ENH) which is designed, implemented and analyzed with the cost effectiveness for both rural and urban areas of Bangladesh and it justifies the applicability of the system in both areas. The designed system is able to meet the energy requirement with renewable energy resources without taking any electricity from grid. In this research, mainly biogas and solar systems are used as hybrid renewable energy sources for the generation of electricity.

Keywords: Biogas, Digester, Energy Neutral Home (ENH), HRT.

1. INTRODUCTION

Bangladesh endowed with plentiful supply of renewable sources of energy. Renewable energy practices in Bangladesh are solar energy, wind energy, biomass energy and hydro-power energy. Solar Energy is inexhaustible and pollution free. It is available everywhere; but the greatest amount is available between two broad band’s encircling the earth between 15" and 35" latitude north and south. Auspiciously, Bangladesh is situated between 20" 43' north and 26" 38' north latitude and as such Bangladesh is in a very favorable position in respect of the utilization of solar energy. Annual amount of radiation varies from 1840 to 1575 kwh/m^2 which is 50-100% higher than in Europe. An agriculture based country like Bangladesh has huge potentials for utilizing biogas technologies. According to estimation 29.7 billion cubic meter of biogas can be obtained from the livestock of the country which is equivalent to 1.5 million tons of kerosene (which is the principal fuel in the rural areas). According to IFRD - there is potential of about four million biogas plants in our country (Akter, 1997), (Islam et. al. 2005). Wind and Small Hydro is suitable for some specific regions. Small Wind Turbines can be installed in the coastal region and off-shore islands of the country. Micro Hydro power plants can be installed in the north-eastern hilly regions and in the existing irrigational canal system with sufficient head. There are scopes of integrated tidal power plants in the coastal regions. But extraction of energy from tidal power is still not proven as cost effective. So, solar and biogas are the most available renewable energy sources throughout the country. In rural areas, people can generate electricity to fulfill their household demand by using their biogas potential and solar. They can produce as much energy as they consume over the course of a year (www.forbes.com, 2009). This is the concept of energy neutral home system. This paper represents an advanced version of previous ENH system where only one source (i.e. biogas) is used but here two or more sources are used as hybrid for the electricity generation by which the reliability is increased (Das et. al. 2012). During daytime the system generates electricity mostly from solar energy and at night from biogas. If any one of the source is unavailable then another one gives support as a backup input source of the system. Thus the higher reliability is achieved by the system.

2. MATERIALS AND METHOD

2.1 Selection of Renewable Energy Sources

Biogas is a renewable source of energy which is used as fuel for cooking, lighting, running vehicles and generators, etc. On the other hand, solar energy is also an excellent natural resource for the electricity generation. Due to the availability of the two sources, this design considered an energy neutral home system with biogas and solar as hybrid energy sources for a home or a residential/commercial area where the energy requirement is met without taking any electricity from grid but the focus is given to cost reduction. The availability of waste is an important factor of the design for biogas generation. To facilitate the availability of waste for biogas generation, the system should have poultry farms, cow farms or other sources of waste.

2.2 System overview

The system to be designed is similar to a small power plant. To design a completely energy neutral system, the renewable energy sources will be taken as the input of the plant. Poultry farms facilitate the waste for biogas

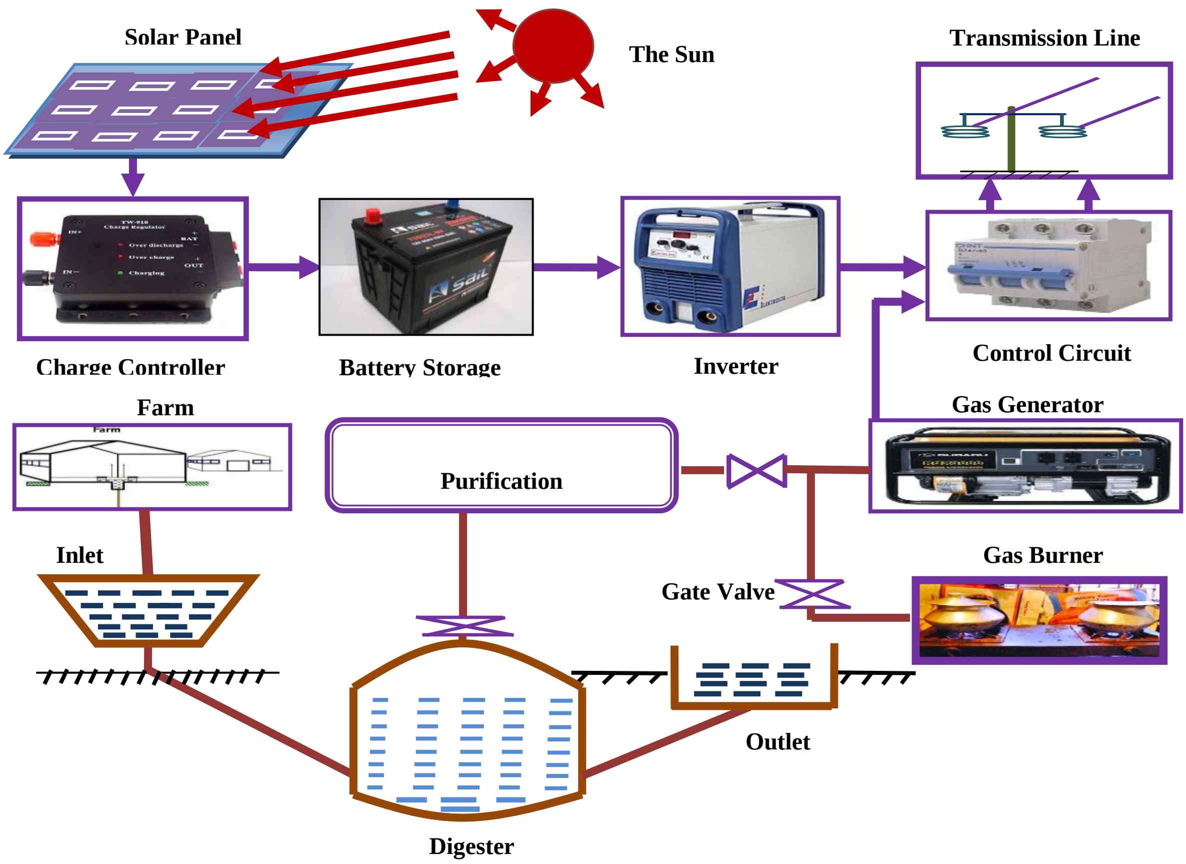

Figure 1 Block diagram of the hybrid ENH system

generation in this system. The chicken manure produces more gas than cow manure because the gas production rate is 0.07 m^3 per kg poultry manure whereas it is only 0.037m^3 per kg cow manure (Chu et. al., 2010), (Gofran et. al., 2007). The total load of the system is calculated and based on the calculated load the digester is designed. With this system all the necessary household energy requirements such as electricity generation, cooking etc. can be easily fulfilled. The system block diagram is shown in Figure 1.

3. SYSTEM DEVELOPMENT

3.1 The Energy Demand Of A Standard Home

In this research an area of 15 houses is considered to make completely energy neutral. The load curve of the hybrid ENH system is shown in Figure 2. From load curve of Figure 2 it is clear that during day time the electricity is generated from solar system and when the sunlight is insufficient then the electricity is generated from biogas. During daytime the biogas burners also run from the biogas plant but at that time the generator will not run. Thus the synchronization is made in the hybrid ENH system.

3.2 Design And Analysis Of Biogas Plant For The Hybrid Enh System

3.2.1 Hens Required In The Farm

a) For electricity generation: Total electricity demand from biogas plant =110.98 kWh. Let for 110.98 kWh electricity generations we required n number of hens.
As an average each hen gives 100 gm of waste. Total waste for *n* number of hens= 0.1n kg. Again, practically 0.07 $m^3$of biogas can be obtained from 1 kg of waste. From each cubic meter we get 1.4 kWh of electricity (Gofran et. al. 2007), (Islam, 2010).
So, from n number of broilers the electricity obtained = 0.01*n* kWh. So, n=11,098 ≈ 11,100.
That means 11,100 number of hens is required to fulfill the demand of electricity of 15 houses. Each house should have poultry farm with 740 hens.

(b) For gas supply: Each family needs two gas burners for cooking purpose and each gas burner consumes 0.4 m^3 gas per hour (Gofran et. al. 2007).
Total gas required for the system = 30 m^3.
So, to produce this gas required no of broiler, *n* = 4,286
Total broilers need for the system = 15,386

3.2.2 Design of Digester

As the digester is the main part of the system, it is designed at first by considering some geometrical assumptions as shown in table 1(LGED, 1999). The design parameters and the design layout are shown in Figure 3 and Figure 4. Considering the Hydraulic Retention Time (HRT) = 40 days (for temperature 30°C).

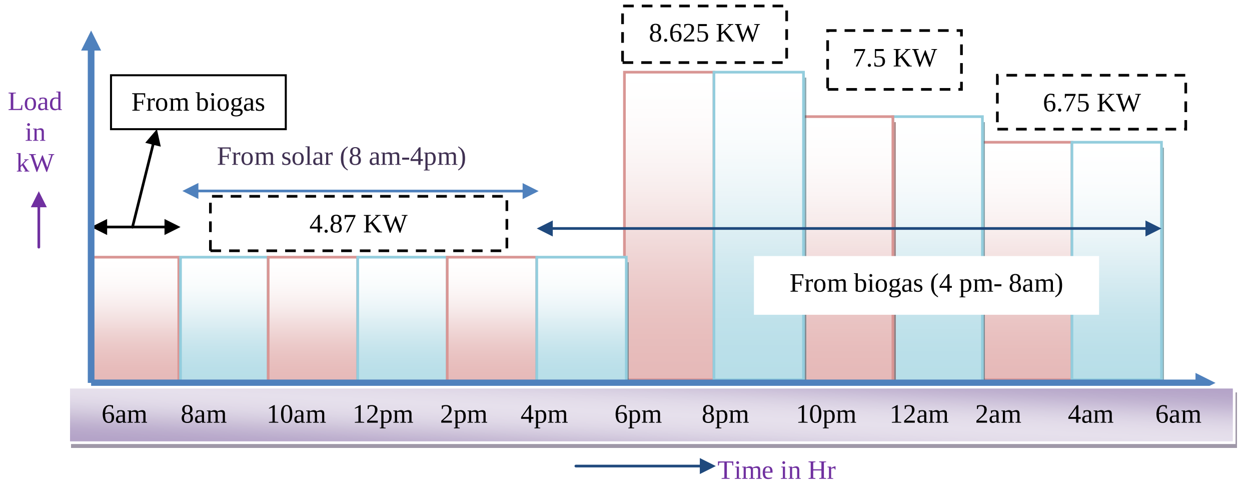

Figure 2 Load Curve of the hybrid ENH system

So, Total discharge=1,110 kg.
TS of fresh discharge = 222 kg
As, 8 kg solid equivalent 100 kg of influent, so, 222 kg solid equivalent = 2,775 kg

Table 1 Geometrical assumptions for digester design

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

So, total influent required, Q = 2,775 kg.
Required water to be added to make TS value 8% = 2,775 – 1,110 kg = 1,665 kg
Working volume of digester=111 m^3
From geometrical assumption: [Table 1]
$V = 140$ m^3 and $D = 1.3078 \times V^{1/3} = 6.79$ m
H = 2.72 m, $f_1 = 0.85$ m, $R_1 = 4.92$ m, $R_2 = 7.21$ m
$V_1 = 25.9$ m^3, $V_c = 7$ m^3.

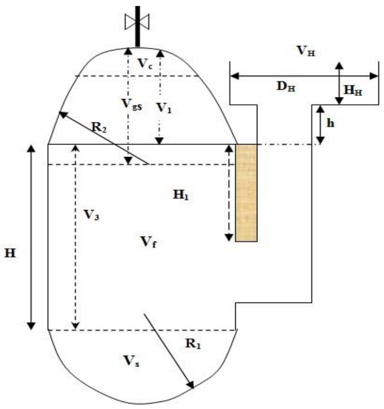

Figure 3 Design parameter of digester

3.2.3 Volume Calculation of Hydraulic Chamber
From assumptions, [Table 1]
$V_c = 0.05V = 7$ m^3 and $V_s = 22$ m^3
So, V_{gs} = Amount of the daily gas yield = TS × gas production rate per kg TS = 77.7 m^3
$V_c + V_1 = 33$ m^3 ,So, out let discharge, $V_{dis} = 2.775$ m^3
Total volume of the gas staying chamber = $V_c + V_1 + V_{dis}$ = 35.775 m^3. Let the normal pressure of the digester is P_i = 4 kPa, height of the hydraulic chamber is h and final pressure after gas being stored = P_f
According to Boyle's law, P_f=12.68kPa
So, $P_f + H\rho g = H\rho g + h_1\rho g + h\rho g$
Or, $h + h_1 = P_f / \rho g = 1.29$ m
Let, height of the hydraulic chamber from digester manure level, h = 0.23 m. So, height of the hydraulic chamber, $h_1 = H_H = 1.29 - 0.23 = 1.06$ m
Diameter of the hydraulic chamber then, $D_H = 2.82$ m.

3.2.4 Digester Size for Supplying Gas
By similar calculation, Volume of digester = 53.575 m^3
Volume of inlet and outlet = 1.07 m^3.

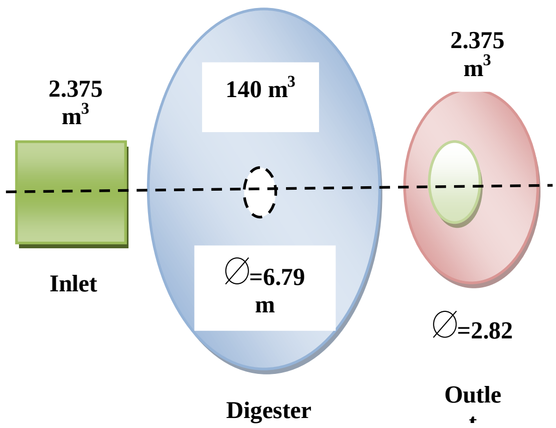

Figure 4 Volume and diameter of digester and hydraulic chamber.

3.3 Design Of Solar Panel And Battery Sizing
(Fahmy et. al. 2010), (Opara et. al. 2011), (Gwamuri et. al. 2009**)**

3.3.1 Solar panel estimation:

Since the loads are run eight hours per day from solar,
So, Energy consumed by these loads = 38.96 kWh⁄day
Let , The days of autonomy is three (3) days and Depth of Discharge (DOD) = 70%, Solar irradiation (G) = 4.2 kWh⁄m^2⁄day and η =55%.
Now, Energy to load (kWh⁄day) = kW rating × G × η_p
So, KW rating = 16.86 KW
If 300 W rating module is selected, Then the number of module will be required ≈ 57

3.3.2 Battery estimation:

If n is the number of days of autonomy, then n×energy supplied to load (Wh/day) = Purchase capacity of battery (Wh) × DOD. So, Wh capacity of battery = 166971.4.
Again, Wh capacity of battery = Ampere Hour (AH) capacity × Terminal Voltage (volt) => AH = 13914.3.
Selecting the size of battery = 200AH@C10.
Then the number of battery required ≈ 70.
Assuming, the number of batteries is 40% of the normal requirement. Number of battery required = 28. So, actual AH used = 5600 AH. Maximum current that could be supplied from the battery bank = 560 Amp. And, load current = 405.8 Amp.

4. SYSTEM IMPLEMENTATION

The establishment of biogas plant is the main part of the hybrid ENH system implementation. The design factors of the system are selection of site, the availability of waste, the nature of waste, the size of the digester, the amount of load and the capacity of the generator. By considering these design factors the location of the system is selected. The address of the selected location is Village: Pomora, Talukder Para, P.S.: Rangunia, District: Chittagong, Bangladesh. The Owner of the selected home is Mr. Anil Kanti Das. Some photographs of the system implementation are revealed in Figure 5 to Figure 10. After completing the whole structure of the designed system, the digester is filled up with the required quantity of waste materials. The waste materials are kept airtight inside the digester till the HRT period for the production of necessary amount of gas. After the HRT period, the pressure of gas inside the digester is sufficient enough to be used for cooking purpose and running the generator.

Figure 5 The base construction of the digester and hydraulic chamber

Figure 7 The complete structure of the digester and hydraulic chamber

Figure 6 The construction of outer structure of the digester and hydraulic chamber

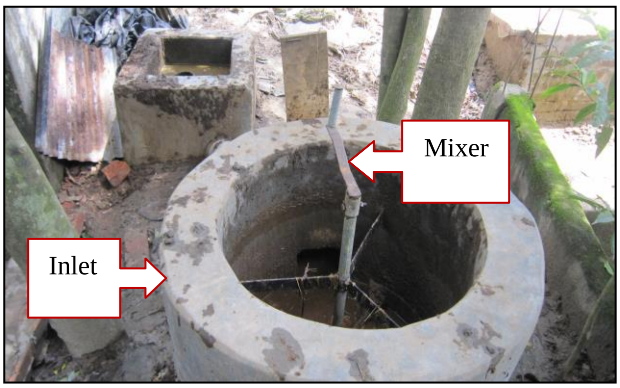

Figure 8 The Inlet of the system with mixer

Figure 9 The stove burns and food is cooked using the gas produced by the system.

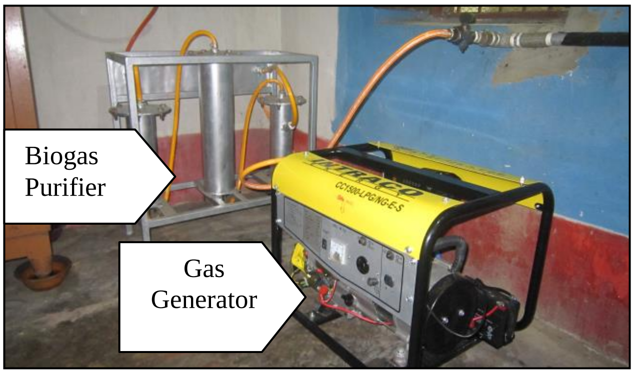

Figure 10 The gas generator with the biogas purifier used in this system.

5. COST CALCULATION OF THE HYBRID ENH SYSTEM

5.1 Installation cost of biogas plant (for electricity generation)

The total cost of biogas plant is depicted in table 2. From implementation of a digester, the cost of a 500 CFT Digester is about 55,000 BDT (Gofran, 2010).
The volume of digester is 140 m^3 or 4,940 CFT.
So, the cost of digester = 5,43,400 BDT
Volume of hydraulic chamber and inlet recharge chamber = 195.8 CFT
So, cost of hydraulic chamber and inlet recharge chamber = 21,543 BDT
Cost of purification unit = 15,000 BDT, Pipe line and others = 20,000 BDT
Cost of two 5kW generators = 1,40,000 BDT and cost of two 2kW generator = 80,000 BDT (Sorkaar, 2010, Ali, 2011).
Total generator cost = 2,20,000 BDT

Table 2 Cost of biogas plant

Digester cost	5,43,400 BDT
Hydraulic chamber cost	21,443 BDT
Purification unit cost	15,000 BDT
Pipe line	20,000 BDT
Generator cost	2,20,000 BDT
Total	8,19,843 BDT

5.2 Cost Of PV System

(a) Solar panel cost:
Recent market price of 300 W panel in Energy Bangla Company = 30,000 BDT (www.energybangla.com, 2011)
So, total solar panel cost (for 57 panels) =17,10,000 BDT
(b) Battery bank cost:
Recent market price of 200 AH battery in Navana group = 18000 BDT (Navana Group Limited, 2011).
So, total battery bank cost (for 28 batteries) = 5,04,000 BDT
(c) Inverter cost:
For this system, 3000 VA inverter with power factor of 0.8 is 28000 BDT (Solarpac company Limited, 2011). Total watt rating of the system is 16860W.
So, number of inverter needed = watt rating ÷ (3000 × 0.8) ≈ 7.
So, total inverter cost = 1,96,000 BDT
(d) Subtotal cost:
Solar panel cost + Battery bank cost + Inverter = 24,10,000 BDT
(e) Miscellaneous cost:
This is the cost of charge controllers, wires, fuses, switches etc. Estimating it by 5% of subtotal cost = 1,20,500 BDT. Total cost of PV system = 25,30,500 BDT

5.3 Total Installation Cost Of Hybrid ENH System

The total cost of hybrid ENH system is summarised in table 3.

Table 3 Total cost of the hybrid ENH system.

Cost of biogas plant	8,19,843 BDT
Cost of solar PV system	25,30,500 BDT
Total cost	33,50,343 BDT

5.4 Installation Cost (For Gas Supply)

The volume of digester is 53.575 m^3=1890.5 CFT
So, the cost of digester = 2,07,955 BDT
Volume of hydraulic chamber and inlet recharge chamber = 75.5 CFT. So, cost of hydraulic chamber and inlet recharge chamber = 8,306 BDT. Cost of purification unit = 10,000 BDT, Pipe line and others = 1, 00,000 BDT
Total cost = 3,26,261 BDT

5.5 Maintenance Cost For 20 Years (For Gas Supply)

Total cost for 20 years, including maintenance cost of purification unit and repairing cost of pipelines = 3,86,261 BDT.
Monthly cost of each family for using gas = 107.29 BDT

5.6 Cost Analysis For Hybrid And Normal ENH System (Gofran, 2010), (Sorkaar, 2010), (Ali, 2011)

5.6.1 Cost analysis for hybrid ENH system:

Installation cost of hybrid plant = 33,50,343 BDT

(a) Maintenance cost of biogas plant per year:

Labor cost per year = 1,20,000 BDT, Repairing cost of transmission line per year = 10,000 BDT, Maintenance cost for 20 years = 26,00,000 BDT

Overhauling cost of generator for 20 years:

Total overhauling cost for two 5 kW generators = 2,75,000 BDT and cost for two 2 kW generators = 1,65,000 BDT.

Total maintenance cost considering overhauling cost = 30,40,000 BDT

(b) Maintenance cost of solar PV system for 20 years:

Battery of PV system has to be changed after 10 years. There is no other maintenance required.

Battery bank cost = 5,04,000 BDT

Total maintenance cost of hybrid power plant = 35,44,000 BDT

So, cost of operation with installation cost for 20 years = 68,94,343 BDT

(c) Per unit cost calculation:

Electricity used per day in kWh = 140.2 kWh, Electricity used per year = 51,173 kWh, Total electricity used in 20 years = 10,23,460 kWh. So, Per unit cost = 6.74 BDT

5.6.2 Cost analysis for ENH system with only biogas

5.6.2.1 *Total cost of the system without operating cost*

(a) Cost of digester:

So, the cost of 188.556 m^3 (6,653.67 CFT) digester = 7,31,903.7 BDT

So, cost of hydraulic chamber and inlet recharge chamber (282 CFT) = 31,020 BDT

Total cost of digester = 7,62,923 BDT

(b) Cost of purification units and pipe line:

Cost of purification unit = 10,000 BDT

Pipe line and others = 10,000 BDT

(c) Cost of generators:

Total generator cost (10 KW, 6 KW and 2 KW) = 2,80,000 BDT

(d) Subtotal cost of system = 10,62,923 BDT

(e) Transmission line cost:

Transmission line cost is 2% of the total plant cost.

So, transmission line cost = 21,258 BDT

(f) Total cost of system without operating cost:

Total cost of the system = 10,84,181 BDT

5.6.2.2 Total cost of the system with operating cost

The total calculated overhauling cost of all generators (10 KW, 6 KW and 2 KW) for 20 years = 5,49,500 BDT.

Total operating cost= pipe line repairing cost + overhauling cost of generator = 5,59,000 BDT

Total cost of the system including operating cost for 20 years = 16,43,181 BDT

Per Unit Cost Calculation:

Total electricity used in 20 years for 51173 kWh = 10, 23,460 kWh.

So, Per Unit Cost = 1.6 BDT

6. EFFECTIVENESS OF HYBRID ENH SYSTEM IN URBAN AREAS

In rural areas there are available places for building poultry farm and cow farm. Availability of poultry waste and cow dung will make it easier to supply electricity only from biogas plant. Again solar PV system is very costly. Most of the rural people have no ability to install a solar PV system. From this chapter, it is clear that the per unit cost of hybrid ENH system is only 6.74 BDT, where for ENH system with biogas is only 1.6 BDT. So, the hybrid ENH system is not cost effective for rural areas. But it will be useful in urban areas because the required land space is less than the normal ENH system.

7. CONCLUSION

Per unit cost of hybrid ENH system is only 6.74 BDT. Also electricity supply is uninterrupted and there is no use of any conventional energy. So, this hybrid ENH system is able to ensure continuous power supply within a reasonable price only using renewable energy sources even in metropolitan city area. This is the time to implement this system throughout the country for removing such worst condition of electricity supply. For this reason, this research is very much important for a country like Bangladesh where the people are facing great power crisis at present.

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