Design and Integrate Dual Renewable Energy in a Residential Building of Urban Area

: A Step Towards the Self–Sustained Smart Energy System for Bangladesh

Mohammad Faisal Matin[1], Shah Md. Istiaque[2]
Dept of Electrical, Electronic and Communication Engineering
Military Institute of Science and Technology
Dhaka, Bangladesh
Email:faisal_eece8@yahoo.com[1], isti712@yahoo.com[2]

***Abstract*—Acute power crisis is an obstacle which Bangladesh is facing tremendously. So a small drive has been taken to solve the power crisis problem by opening a new arena by producing electricity through hybrid system of solar and biogas in a dense urban area. The possible biogas and solar power generation is calculated for multistoried building of Dhaka keeping the aim in mind that if this sorts of projects are made popular then it can save a huge amount of electricity by providing to the grid which may enhance our garments potential as a whole industrial potential. Environmental position of Dhaka is poorest in world perspective. So by applying hybrid system by renewable energy, we can improve the environmental aspect tremendously as well. Different types of solar modules have been analyzed in this paper. Power generation using biogas has been incorporated and the potentiality of various types of wastes has been analyzed. This paper evolves using of maximum unused area for producing power in a multistoried building of an urban area like Dhaka.**

Keywords—smart grid ; PV; solar energy;biogas

I. INTRODUCTION

To meet present power crisis, using of green energy is the best solution. At present there is huge number of residential building in Dhaka city. There is also available space in the roof top that are remain unused. The unused space on the roof can be used for producing electricity by solar panels. A small biogas plant can also be set up if there are available free spaces. To design the system we have selected a fourteen storied building situated at Mirpur-12, named **Polash**. The available roof-top area is 6370 sft for installing solar panel. There is also available space to set up a small biogas plant. But for biogas production we have to consider the environmental effect and availability of raw materials. Output power from this hybrid system will be injected to the national grid .A bi-directional energy meter will be used to record the power injected to the grid from the hybrid system and also the power consumed by the dwellers of the apartment. The bill for the electricity units injected to the grid will be deducted from the monthly electricity bill of the consumer.

II. EFFICIENCY AND PERFORMANCE OF GRID CONNECTED PV SYSTEMS

A. Smart Grid-Connected Solar Systems

The smart grid is a digital network that unites electrical providers, power-delivery systems and customers, and allows two-way communication between the utility and its customers. The smart grid allows utility customers to play a bigger role in their power usage, encourages them to use power wisely and efficiently. The advanced distribution system should be smart grid to minimize the cost, improve system reliability and power quality.Smart energy demand mechanisms and tactics includes

- Supervisory control and data acquisition (SCADA) system
- Flexible alternating current transmission systems (FACTS)

B. Optical Tilt Angle

To avoid excessive shadowing, the arrays have to spaced apart by a distance d, in relation to the module width a, $d/a=\cos\beta+\sin\beta/\tan\varepsilon$. Here β means optical tilt angle. Shadowing angle ε can be expressed by the geographical latitude ϕ and the ecliptic angle δ, $\xi = 90° - \phi - \delta$. Fig. 1 shows arrangement of a large number of rows of modules.

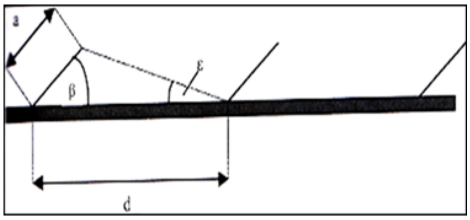

Fig. 1. Arrangement of a large number of rows of modules [1]

C. Final Yield

For grid-connected PV systems the energy yield measured by a separate AC meter at the inverter exit. Its dimension is kWh. The final yield, $Y_F = E_{USE} / P_N$ (kWh/kW) . Here E_{USE} = energy yield measured by a separate AC meter, P_N = nominal power of the solar generator.

D. Performance ratio

The Performance Ratio (PR) is a dimensionless figure as a measure of system efficiency. In practice, it is specified in percent and describes the effectiveness of the PV system compared with a PV system that operates under nominal operation condition without any losses. Performance Ratio, PR= Y_F / Y_R, Y_F =final yield [kWh/kW], Y_R = irradiation at solar module area during the considered time [kWh/m^2] divided by the irradiation under STC (1,000/ m^2).

III. SYSTEM ARRANGEMENT OF SOLAR PANEL

A. Site Area Calculation

The total rooftop area of the selected 14 storied building is 6370 sft. The area of the stair room+ machine room + meeting room = 450 sft, void area + parapet wall =235 sft. Available open space = 5685 sft. Loss area = 5% of the available open space = 285 sft. So the area used for installing solar panel = 5400 sft.

B. Tilt Angle Calculation & Row Distance Calculation

In order to maximize the panel efficiency tilt angle β must be adjusted in such a way that it will get the maximum radiation.

$$\beta = 0.76 \times \text{Latitude} + 3.1° \quad (1)$$

For Dhaka, ϕ = 23.723° and ecliptic angle δ = 23.5°. So β = 21.13° = 21°. One of the boundary conditions for the installation and performance of PV modules is to determine the correct distance between two consecutive arrays. Now ε and d/a are calculated, ε =90º-23.723º-23.5º =42.77º, so d/a= cos21º +sin21º / tan42.77º = 1.32. 200 W Mono-crystalline solar module from electro solar company [2] and 20 kW grid connected solar inverter with high efficiency have been selected for system designing [3].

C. Integrating the components

From the specification of mono-crystalline [2] solar module, module width a= 1.58m =5.18 ft =5 ft 2 inch, module length = 0.808 m= 2ft 8 inch= 2.65 sft. It was found that d/a = 1.32, so d= 1.32 ×5.18 ft= 6.84 ft= 6 ft 10 inch. Minimum spacing between two consecutive array to avoid shadowing = 6.84 -5.18 ft =20 inch. Let minimum spacing between two module in a single array = 6 inch.

Using AutoCAD software, from Fig. 2 it was found that the maximum number of modules that can be mounted on the roof is 230.

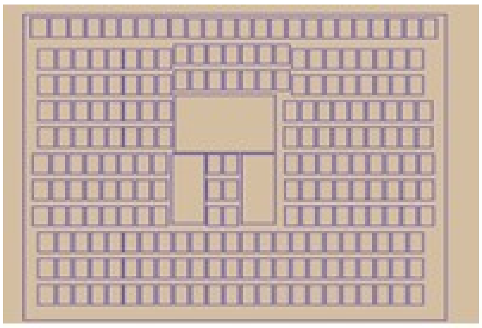

Fig. 2. System arrangement of solar panels on the roof top by AutoCAD design.

From the manufacturer specification, maximum DC input voltage for grid tied inverter = 360 volt [3].Optimum operating voltage of PV module = 34.4 volt. So there will be 10 modules in an array and 23 no of arrays to be connected to the inverter. PV combiner box is used to reduce connection to the inverter. In our design, each combiner box can simultaneously access 6 PV arrays. So 4 combiner boxes are required to connect 23 arrays.

IV. TOTAL SOLAR POWER

A. Average Incident Solar Radiation

Average incident solar radiation of one year at Dhaka is shown in table 1.

TABLE I. THE AVERAGE INCIDENT SOLAR RADIATION

Month	Average incident solar radiation (kW/m^2)
January	0.174
February	0.195
March	0.231
April	0.236
May	0.232
June	0.186
July	0.162
August	0.172
September	0.196
October	0.165
November	0.177
December	0.169
Annual average	0.191

B. Calculation of module efficiency

$$\eta = (I_{sc} \times V_{oc} \times FF)/P_{IN} \quad (2)$$

Here η = module efficiency, Isc = short circuit current,Voc= open circuit voltage ,FF= fill factor = (Vmp× Imp)/(Isc × Voc), Vmp = optimum operating voltage, Imp = optimum operating current, P_{IN}= input solar power.

C. *Output Power of Different Types of Modules*

1) Monocrystalline solar module: From the technical specifications at STC(at 25°C and AM1.5) Isc = 6.5A,Voc= 43.2V,Vmp= 4.4V,Imp=5.81A . So fill factor FF= 0.71. Dimensions of the module = 1.58×0.808×0.035 m^3, Pin= 1000 × 1.58 × 0.808 W =1277 W. From these values ,efficiency of monocrystalline solar module is calculated as **η = 15.61 %**.

The monthly average output power from the solar module and the total system output will now be calculated.

$$P_{pv} = Y_{pv} \times f_{PV} \times (G_T / G_{T,STC}) \qquad (3)$$

Ypv= output power under standard test conditions [kW],fpv= the PV derating factor [%], G_T= the solar radiation incident on the PV array in current time step [kW/m^2],$G_{T,STC}$= the incident radiation at standard test conditions. So peak output power of the designed system, Ypv =200× 230 W= 46kW,f_{PV} = 0.8,$G_{T,STC}$ = 1 kW/m^2.In January G_T= 0.174 kW/m^2. So Ppv = 6.40. So, total hours of operation in a year = 4380 hrs/yr(daily 12 hrs). Average solar energy production /yr = **30792** kWh/yr.

2) Polycrystalline solar modules: At STC (at 25°C and AM1.5) fill factor FF= 0.73, Dimensions of the module = 1.482 × 0.992× 0.035 m^3 [2], .P_{IN}= 1470 W, so **η = 13.5%**. In January Ppv = 5.71kW.

3) Thin Film solar modules: At STC (at 25°C and AM1.5),fill factor FF= 0.722,dimensions of the module = 1.956×0.992× 0.05 m^3 ,P_{IN}=1940W, so **η = 11.1%.**In January, Ppv = 4.86 kW.

V. COST ANALYSIS FOR THE SOLAR SYSTEM

A. *Capital Cost*

Capital cost of monocrystalline solar module is shown in table 2.

TABLE II. CAPITAL COST CALCULATION FOR GRID –CONNECTED SOLAR PV ARRAY SYSTEM [4]

Name of the Item	Price in USD
Solar PV array	69000
Grid connected solar inverter	3730
PV combiner box	5000
Solar panel bracket	5000
	Total capital cost = 82730

B. *Operation And Maintenance Cost*

The operation and maintenance cost of solar system would be about 1% to 3% of capital cost per year over the first 20 years [5]. For this system it is taken 3% of the capital cost. So the operation and maintenance cost of this system is = 2481.9 USD/yr.

C. *Total Revenue Calculation*

Sell-back price policy of foreign countries has been followed in this analysis. For example in Queensland, Australia, it is two times higher than the electricity price charged by the electricity supplying companies [6], [7]. The latest retail tariff in Bangladesh for residential consumers (consuming between 300- 400 units) = 4.93 taka per unit=0.0632 USD per unit (**1 USD=78.00 Taka**) .So sell-back price is taken as = 2×0.0632 USD = 0.1264 USD. In all further calculations, it is used. So, the revenue earned by selling total electricity = **3892.1** USD/yr. Capital cost of poly-crystalline and thin film solar module is **56890 USD** and **60210 USD** respectively. This indicates that mono-crystalline solar panel has the highest price and poly-crystalline solar panel has the lowest price. So polycrystalline solar panel is most feasible for the system. But mono-crystalline solar panels are the best in consideration of power. For this reason we selected it for our design purpose.

VI. BIOGAS

A. *Biogas*

Biogas is gaseous mixture of methane, carbon dioxide, hydrogen sulphids and several other gases, produced by anaerobic fermentation of organic material such as animal and human manure, leaves, industrial waste, etc.

B. *Design Parameters*

1) Hydraulic Retention Time (HRT): Hydraulic retention time of manure is the number of days during which we get a considerable amount of gas. In the climate of Bangladesh a certain amount of manure can produce gas within 40-45 days [8].

2) Total Solid (TS): Total solid indicate the amount of material without considering the liquid part. Most favorable TS value desired is 8% for smooth fermentation process .

Fig. 3 shows relationship between temperature and HRT (For constant TS value of 8%). This shows that when temperature increases, HRT value decreases.

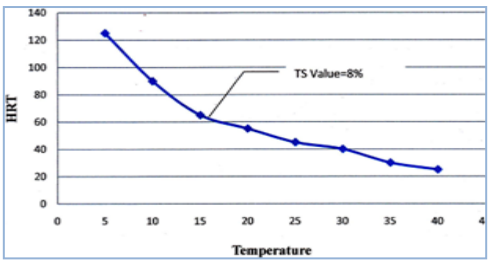

Fig. 3. Temperature Vs. HRT curve at constant TS value [9].

3) C/N Ratio: It is the carbon to nitrogen ratio. Favorable range of C/N ratio is from 20:1 to 30:1 to have proper biogas production capacity [10][8].

VII. DESIGN OF BIOGAS PLANT FOR A SINGLE HOUSE

A. *Calculation of Electricity Generation*

From analysis it was found that 1W electricity is produced from one broiler [11] and 50 W electricity is produced from one cow for 10 hours/day electricity consumption [11].

B. *Energy Demand of A Standard Home*

Here a biogas plant will be designed for a single house. The used loads in the design are seven energy saving bulbs (two bulbs of 12 W, three bulbs of 15 W and two bulbs of 25 W), four ceiling fans (75 W), one color TV (100 W) and one refrigerator (150 W). Taking the HRT value of 40 days, 0.07 m^3 gas is produced from 1 kg poultry waste where the waste to water mixing ratio is l:2 [12].

C. *Design of biogas plant*

For the above load, gas containing capacity of $4m^3$ is essential which needs a poultry farm of about 800 broilers or a cow farm of 16 cows. The biogas plant design mainly consists of digester design and design of hydraulic chamber. Fig. 4 shows digester cross section.

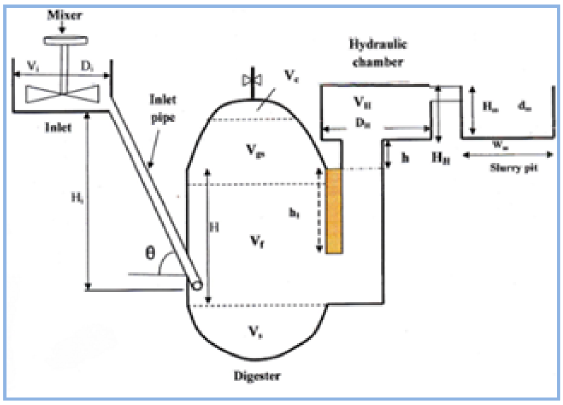

Fig. 4. Shematic diagram of biogas plant

Here, volume of inlet=Vi, volume of gas collecting chamber=Vc,volume of gas storage chamber=Vgs, volume of fermentation chamber =V_f ,volume of sludge layer=Vs, volume of hydraulic chamber=V_H.Total volume of digester V=Vc+Vgs+V_f+Vs,diameter of inlet=Di, diameter of digester =D,diameter of hydraulic chamber = D_H, depth of slurry pit = dss,height of inlet pipe from inlet chamber to down level = Hi, height between lower level of gas storage chamber and sludge layer =H,height of the hydraulic chamber from digester manure level =h_1,height of the hydraulic chamber to lower level of gas storage chamber = h,height of the hydraulic chamber =H_H , the inclined angle of inlet pipe =θ. Different measurement parameters of digester is shown in fig. 5.Geometrical assumption for the digester design is shown in table 3.

TABLE III. GEOMETRICAL ASSUMPTION FOR DIGESTER DESIGN [10]

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

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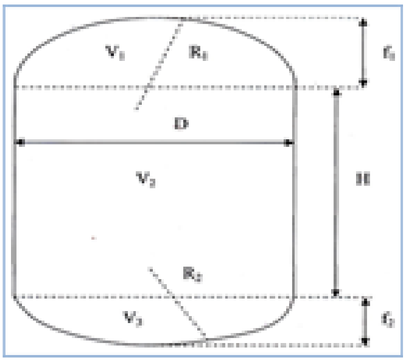

Fig. 5. Different measurement parameters of digester

1) Volume calculation of digester chamber : Every broiler or layer hen gives 100 gm manure per day. So total discharge = 800 × 0.1 kg = 80 kg. TS of fresh discharge = 0.2×80 kg =16 kg .To make the TS value of 8% , additional water has to mixed with fresh discharge.16 kg solid equivalent , Q =200 kg. Required water to be added =120 kg. Here HRT =40 days.Working volume of digester.

$$Vgs+ V_f = Q \times HRT = 8000 \text{ kg} = 8 \text{ m}^3 \tag{4}$$

From geometrical assumption , Vgs+V_f = 80% V. So From (4) 8=0.8V, so V = $10m^3$ and D = 1.3078 $V^{1/3}$ =2.82 m. Now

$$V_3=(3.14\times H \times D^2)/4$$
$$\text{or,}0.3142D^3=(3.14\times D^2 \times H)/4$$
$$\text{or, } H = 1.13 \text{ m} \tag{5}$$

As the value of D and H is now known. So, f_1= 0.564 m, f_2 = 0.3525 m, R_1=2.04 m, R_2= 3m,V_1=1.85 m^3.The value of inclined angle of inlet pipe θ = 60 [8].

*2) Volume Calculation of Hydraulic Chamber:*From assumptions, Vc=0.05V =0.5 m^3

$$Vs = V - (Vgs + V_f + Vc)$$
$$= 1.5\ m^3 \tag{6}$$

So, amount of daily gas yield, Vgs =TS× gas production rate per kg TS = 16 × 0.35 m^3 per kg TS = 5.6 m^3 and Vc+ V_1 =2.35 m. Now, the discharge of outlet should be the same of inlet recharge. So, outlet discharge, Vdis = 0.2 m^3.Total volume of the gas staying chamber = Vc+V_1+Vdis = 2.55 m^3. Let the normal pressure of the digester is Pi=4 kpa .Final pressure after gas being stored = P_f. The product gas should have to stay within 2.55 cubic meters volume. So according to Boyle's law

$$Pi \times (\text{total gas produced} + 2.55) = P_f \times 2.55$$
$$\text{or, } 4 \times (5.6 + 2.55) = P_f \times 2.55$$
$$\text{or, } P_f = 12.78\ \text{kPa} \tag{7}$$

Let, height of the hydraulic chamber is h. The pressure of the hydraulic chamber should be 12.78 kPa so that only the inlet recharge will discharge.

$$P_f + Hpg = Hpg + h_1 pg + hpg$$
$$\text{or, } h + h1 = P_f/Pg = (12.78 \times 1000)/1000 \times 9.81$$
$$= 1.3\ m \tag{8}$$

Let, height of the hydraulic chamber from digester manure level, h_1= 0.3 m. So, height of the hydraulic chamber to digester manure level, h = 1 m. Let H_H = 1m, if D_H is the diameter of the hydraulic chamber then.

$$\pi \times (D_H/2)^2 \times H_H = 0.2$$
$$\text{or, } D_H = \sqrt{(4 \times 0.2/\pi \times H_H)}$$
$$= 0.167 \tag{9}$$

Fig. 6 shows design layout of digester based on poultry waste.

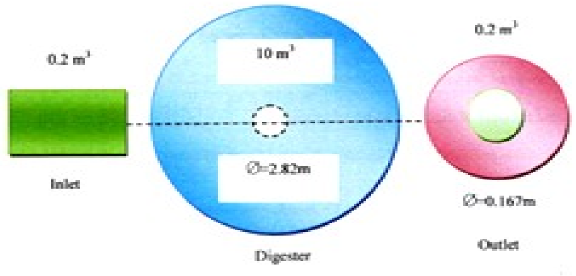

Fig. 6. Design layout of digester, inlet and outlet based on poultry waste.

VIII. Biogas Plant Design for the Proposed Hybrid System and Cost Analysis

Layout of the digester for the proposed system is designed using 15 kW generator basing on poultry waste. Design parameters are calculated accordingly for a single house. Two generators (10 kW and 5 kW) are incorporated in the system instead of one to increase reliability. Fig. 7 shows layout of biogas plant for 15 thousand layers.

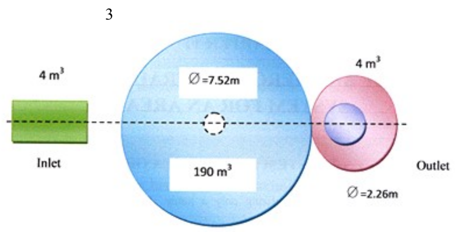

Fig. 7. Top view of digester for 15 thousand layers.

Total produced electricity from biogas is tabulated in table 4.

TABLE IV. Generator Capacity Selection

Designed for	Gas production capacity (m^3)/ day	Generator capacity(kW)	Time of electricity supply (Hour)	Unit of electricity (kWh)
I5 thousand layer	105	10	10	100
		5	10	50

A. Cost Calculation

1) Digester: The cost of a 500 CFT Digester is about 705.13 USD [13] .The volume of digester is 190 m^3 = 190 × $(3.28)^3$ CFT = 6,704.6 CFT. So, the cost of Digester = 9455.20 USD. Volume of hydraulic chamber and inlet recharge chamber = 282 CFT. So, cost of hydraulic chamber and inlet recharge chamber = 397.7 USD. Total cost of digester = 9852.9 USD.

2) Cost of purification Unit and Transmission line: Cost of purification Unit is=134.62 USD. Pipe line and others = 66.66 USD. Transmission line Cost is 2% of the total plant cost. Subtotal cot of the plant= 13131.10 USD. So, Transmission line Cost =262.62 USD. Total cost of the system= 13393.72 USD.

3) Cost of generator: Cost of 10 kW and 5 kW generator is 2179.49 USD and 897.44 USD respectively [14],[15].

B. Net income

Electricity consumption per day = 150 kWh. Income per year = 6826.15 USD. Repairing cost of transmission line per year = 166.66 USD. Net income per year = 6659.48 USD. Income in 20 years = 133189.74 USD.

C. Overhauling Cost of Generator for 20 years

Overhauling of a generator is required after 10,000 hours of operation which is called top overhauling. Another overhauling has to be done after further 10,000 hour operation which is called major overhauling. The cost of top overhauling and major overhauling is about l5% and 50% of the generator cost [14].For the generators, operating time will be 72,000 hours (20 years). So four times top overhauling and three times major overhauling have to be done. For 10 kW generator, top overhauling cost for one time = 327 USD. Total top overhauling cost = 1307.7 USD. Major overhauling cost for one time = 1089.75 USD. Total major overhauling cost = 3269.23 USD. For 5 kW generator, top overhauling cost for one time = 15% of 897.44 = 134.62 USD. Total top overhauling cost = 538.46 USD. Major overhauling cost for one time = 50% of 897.44 =448.72 USD. Total major overhauling cost =1346.16 USD. Total overhauling cost of 10 kW and 5 kW generator = 4576.94 and 1884.62 USD respectively. Overhauling cost of generators for 20 years =6461.56 USD.

D. *Total operating cost*

Repairing cost = 166.67 USD. Total operating cost = repairing cost + overhauling cost of generator = 6628.23 USD.

E. *Per Unit Cost*

So net income considering the overhauling cost of generator after 20 years = 126561.51 USD .Electricity produced in a day =150 kWh. Total electricity produced in 20 years = 10, 80,000 kWh. Total cost = 6628.23 +13393.72=20021.95 USD.

Per Unit Cost = 20021.95 / 10, 80,000 = **0.0185388** USD/kWh=**1.45** BDT/kWh.

IX. RESULT AND INTEGRATION

A. *Result*

For solar system, total capital cost = 82730 USD. Operation and Maintenance Cost for 20 years= 49638 USD. Total Cost= 132368 USD. Total solar energy production for 20 years = 6, 15,828 kWh.

From biogas, it was found that total electricity produced in 20 years = 10, 80,000 kWh and total cost =20021.95 USD.

B. *Integration*

Total energy production from this hybrid system in 20 year= **16, 95,828** kWh. Total cost of the hybrid system=**152389.95** USD.

Per Unit Cost of the hybrid system = 152389.95 / 16, 95,828 = **0.09** USD/ kWh= **7.02** BDT/ kWh**.**

X. CONCLUSIONS & SUGGESTIONS FOR FUTURE WORKS

A. *Conclusions*

This paper is a study of commercial application of grid-connected hybrid power system for a high rise building on densely populated areas. Though output power from individual building is small, significant power can be drawn from this system if it is installed in a large number of buildings. In this paper grid-connected power system was used instead of off-grid power system. The reason behind is that the solar storage battery has very poor reliability compared to other solar system equipment. If other features of the smart energy system are added to this existing system, our hybrid system design can be a glaring example of smart energy.

B. *Suggestions For Future Works*

- Implementation of solar panels to the façade of southern portion of the building can increase the electricity generation.
- Biogas can be used for cooking system of whole building by which huge amount of natural gas can be saved.

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