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Design and Integrate Dual Renewable Energy in A Residential Building of Urban Area: A Step towards the Self–Sustained Smart Energy System for Bangladesh

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DECLARATION

The thesis titled " **Design and Integrate Dual Renewable Energy in A Residential Building of Urban Area: A Step towards the Self–Sustained Smart Enegy System for Bangladesh."** is the outcome of the investigation carried out under the supervision of Professor Dr. Mohammad Jahangir Alam, Department of Electrical and Electronic Engineering (EEE), Bangladesh University of Engineering and Technology (BUET), Dhaka. It is also declared that neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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DEDICATION

TO OUR BELOVED PARENTS

AND

OUR HONORABLE TEACHERS

ACKNOWLEDGEMENT

With due gratefulness, the authors would like to convey their gratitude to Almighty Allah as He has made this thesis work possible.

The authors would like to express their sincere gratitude to their thesis supervisor Dr. Mohammad Jahangir Alam, Professor, Department of Electrical and Electronic Engineering (EEE),Bangladesh University of Engineering and Technology (BUET) for his continuous guidance, encouragement, valuable suggestion and inspiration. His sincere and wise advice helped the authors greatly to make the work successful. Without his initiatives this thesis would not have been possible.

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ABSTRACT

This thesis proposes a solar photovoltaic and biogas hybrid smart energy system for generation of electricity. To overcome from global warming effect, economic and statistical impact on prosperity and dependency this hybrid system energy has a higher reliability, can be cost effective.

Acute power crisis is an obstacle to that 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 than 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 renewable hybrid system we can improve the environmental aspect tremendously as well.

Different types of solar modules, effect of temperature and concisely the cooling system in power generation have been analyzed in this thesis paper.

Power generation using biogas have been incorporated and the potentiality of various types of wastes have been analyzed.

This thesis evolves to use the maximum unused area for utilizing power generation in a multistoried building of an urban area like Dhaka.

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LIST OF ABBREVIATIONS

BDT	Bangladeshi Taka
CFT	Cubic Feet
C/N	Carbon/Nitrogen
CNG	Compressed Natural Gas
HRT	Hydraulic Retention Time
LPG	Liquefied Petroleum Gas
MMCF	Million Cubic Feet
NMOC	Non Methane Organic Compound
NG	Natural Gas
PV	Photovoltaic
TVS	Total Voltaic Solid
TS	Total Solid
DC	Direct Current
IC	Internal Combustion Engine

CHAPTER 1

INTRODUCTION

1.1 Hybrid System

Hybrid Power Systems incorporate several electricity generating components with usually one major control system which enables the system to supply electricity in the required quality. Power generated by the PV array during the day is stored in the battery bank through an energy manager, which controls the complete system. Diesel generators are expensive to run, and may also require frequent maintenance support. A judicious mix of solar and other renewable technologies, coupled with a diesel generator / grid, can offer a techno-commercially viable solution that will power the backbone of rural connectivity. The resultant hybrid system thus offers an optimal solution at a substantially lower cost. It is ideal for electrification of remote villages in Bangladesh. Cutting edge technologies based on latest research to integrate dual power sources in the most ideal way. In figure 1.1 a hybrid power system is shown .

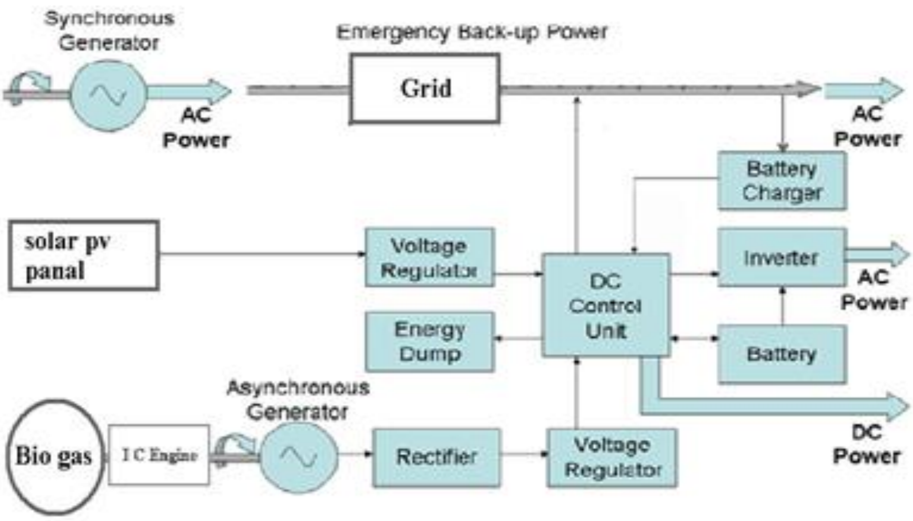

Figure 1.1: A hybrid power system

1.1.1 Working Principle of Hybrid Power System

The power from solar is combined with biogas generation. The output is stored in the battery bank. This energy is drawn by the electrical loads through the inverter, which converts DC power into AC power. The inverter has in-built protection against short-circuit, overheating, low battery voltage and overload. The battery bank is designed to feed the loads up to a certain number of days with no sun or wind/biogas, depending upon the system requirement.

The solar panel is the power source of all photovoltaic installation. Photovoltaic (PV) are solid- state, semi-conductor type devices that produce electricity when exposed to light. The word photovoltaic actually means "electricity from light." Many hand-held calculators run off power from room light, which would be one example of this phenomenon. Larger power applications for this technology are also possible.

Biogas is a type of gas that is formed by the biological breakdown of organic matter in an oxygen deficient environment. It is counted as an eco-friendly bio-fuel. Biogas contains 60% methane and carbon dioxide. It can be employed for generating electricity and also as automotive fuel. Biogas can be used as a substitute for compressed natural gas (CNG) or liquid petroleum gas (LPG).

1.1.2 Other Hybrid Combination

The wind generator starts generating power when wind reaches the cut-in speed of 3m/s and the wind turbine is self-regulated with a patented pitch control mechanism which guarantees a stable energy output during strong winds. It also ensures storm protection and during very windy periods, the excess energy is dissipated through a dump load, which can be used for heating purposes.

Solar complementary system makes use of solar and wind power to generate electricity simultaneously, therefore it can utilize weather resources more effectively. In appropriate weather conditions, wind and solar complementary system can improve the continuity and stability of generation. As there is always strong wind at night, the product can complement well, it would reduce the system's solar panel deployment and greatly cut the cost. The initial investment and generation cost of system's unit capacity are lower than independent photovoltaic system [1].

1.2 Background

To meet present power crisis, using of green energy (renewable) is the best solution. At present there is huge number of residential building in Dhaka city. There is also a 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 some available free spaces. So a small hybrid power plant can be set up in a residential building.

To design the system we have select a fourteen storied building situated at Mirpur cantonment at Mirpur-12, named "**Polash**". We have planned to install the solar panels on the roof top of the building. The available roof-top area is 6370 sft.

There is also available space for a small biogas plant. But for biogas production we have to consider the environmental effect and availability of raw materials. For biogas generation, gas generator will be used.

The major portion of the output power from these panels will be injected to the national grid and rest will be stored in batteries to supply emergency load. 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.

1.3 Objectives

i. Optimization of the utilization of the unused area of the building cost effectively.
ii. Designing the roof-top with solar panel, calculation of total power generation from this system and it's cost.
iii. Technical and cost analysis of Mono-crystalline, poly-crystalline and thin-film solar cells.
iv. Analysis the effect of temperature upon solar cells.
v. Implementation of cooling system.
vi. Designing of biogas plant for the building.
vii. Technical and cost analysis of various wastes.
viii. Cost analysis for this bio gas plant for real implementation.

1.4 Thesis layout

The thesis includes twelve chapters. Chapter one is the introduction of the thesis. This chapter includes a brief introduction about hybrid power system, background of the thesis and objective of this thesis.

Chapter two describes about photovoltaic solar cell, its working principle. It also includes discussion about grid connected system, decentralized grid-connected PV systems, central grid-connected PV systems, smart grid-connected solar systems. This chapter also gives idea about geometrical considerations and optical tilt angle. This chapter also contains detailed discussion about different types of installation possibilities of solar panels. These are Installation on a flat roof, installation on a sloped roof , installation on a facade , mounted on racks etc. This chapter also describes about important parameters of solar panels. These are final yield, performance ratio. This chapter also includes discussion about long-term behavior of the main components of a PV system. These components are solar module ,inverter, mounting racks and fixing materials, cables.

Chapter three starts with the introduction of biogas, discussion of different stages methane production, factors affecting Methane production. It also describes effectiveness of renewable energy based home energy system in Bangladesh, system overview of biogas plant, components and operation of designed renewable energy based home system, control circuit, transmission line and other associate parts. There is also discussion about origin of biogas, composition and properties of biogas. The steps of biogas production is also discussed in this chapter.

Chapter four describes system arrangement of the PV solar module for which site area calculation ,tilt angle calculation & row distance calculation has been shown. This chapter also describes the details of components for the arrangement . These are PV module details, sizing the inverter, sizing the battery, charge controller rating. chapter . Connecting accessories and safety components are also discussed in this chapter , these includes PV combiner box, mounting structures, filter. Integrating the components sequentially are also described in this chapter.

Chapter five is the calculation of total solar power. Average incident solar radiation of Dhaka is given in this chapter. This chapter includes different types of calculation. This are : calculation of module efficiency, average output power calculation. The Monthly average output power for monocrystalline solar module is given in this chapter. There is also detailed calculation of output power for polycrystalline solar modules and thin film solar modules

Chapter six is cost analysis of the system and comparison of various solar cells. Description of different types of cost are given in this chapter. These are capital cost, replacement cost and operation and maintenance cost . total cost calculation & total revenue calculation are also shown in this chapter. There is also shown comparison among three types of modules. These are cost comparison, revenue comparison.

Chapter seven is shows the effect of temperature on solar cell. Temperature dependence of solar cell, output power vs. temperature, output power variation with temperature is described detailed in this chapter. Heat absorbing methodology, how the cooling system works, cooling system arrangement is also described in this chapter.

Chapter eight includes calculation of electricity generation from different types of waste. Calculation of electricity generation from poultry waste, calculation of electricity generation from cow dung, calculation of electricity generation from human waste is shown in this chapter.

Chapter nine shows design of biogas plant for a single house. Design parameters are given in this chapter. These are hydraulic retention time, total solid , fresh discharge, liquid part, relationship between temperature and HRT, C/N ratio . Biogas plant design is also done in this chapter. These are volume calculation of digester chamber, volume calculation of hydraulic chamber. Design of biogas plant is shown separately for poultry waste & cow dung.

Chapter ten shows design of biogas plant for a multistoried building. Design of digester for 15 thousand layers, 20 thousand layers, and 140 cows are shown separately. Cost calculation are also shown in this chapter. This includes cost of digester, cost of purification and units and pipe line, cost of generator, transmission line cost. Then total cost of the system is also calculated. Per unit cost is also calculated in this chapter.

Chapter eleven contains results and discussion.

Conclusive discussion & suggestions are drawn in chapter twelve.

And at the last portion of the thesis consists of references and appendix.

CHAPTER 2

GRID-CONNECTED PV SYSTEMS: IT'S INSTALLATION POSSIBILITIES, EFFICIENCY AND PERFORMANCE

2.1 Photovoltaic

Photovoltaic (PV) are solid-state, semi-conductor type devices that produce electricity when exposed to light. The word photovoltaic actually mean "electricity from light." Many hand-held calculators run off power from room light, which would be one example of this phenomenon. Larger power applications for this technology are also possible.

2.1.1 Working Principle of Photovoltaic

Photovoltaic are the direct conversion of light into electricity at the atomic level. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured electric current results that can be used as electricity.

The photoelectric effect was first noted by a French physicist, Edmund Becquerel, in 1839, who found that certain materials would produce small amounts of electric current when exposed to light. In 1905, Albert Einstein described the nature of light and the photoelectric effect on which photovoltaic technology is based, for which he later won a Nobel Prize in physics. The first photovoltaic module was built by Bell Laboratories in 1954. It was billed as a solar battery and was mostly just a curiosity as it was too expensive to gain widespread use. In the 1960s, the space industry began to make the first serious use of the technology to provide power aboard spacecraft. Through the space programs, the technology advanced, its reliability was established, and the cost began to decline. During the energy crisis in the 1970s, photovoltaic technology gained recognition as a source of power for non-space applications.

Figure 2.1 illustrates the operation of a basic photovoltaic cell, also called a solar cell. Solar cells are made of the same kinds of semiconductor materials, such as silicon, used in the microelectronics industry. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other.

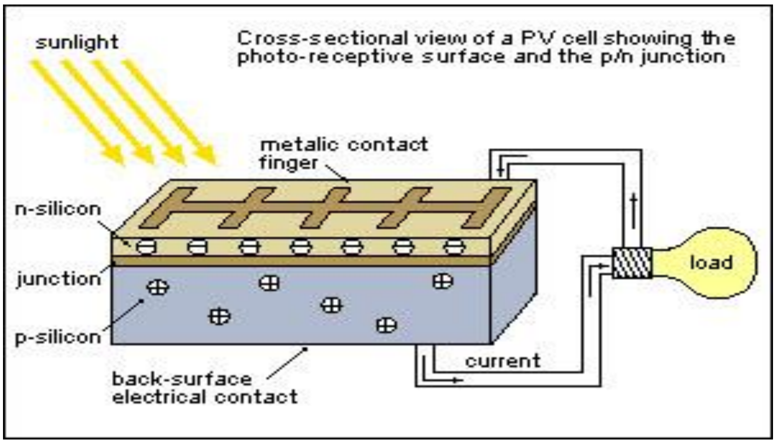

Figure 2.1: Working principle of a PV cell

When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current that is, electricity. This electricity can then be used to power a load.

2.1.2 Different types of Photovoltaic Systems

A photovoltaic system (or PVS) is a system which uses solar cells (arranged into solar panels) to convert sunlight into electricity. And two type of connection as following

1) Solar Grid Tie Systems
2) Solar off grid & cabin system

A PVS consists of many components. These include solar cells, mechanical and electrical connections and mountings and means of regulating and modifying the electrical output. Figure 2.2 below shows a simple PV system.

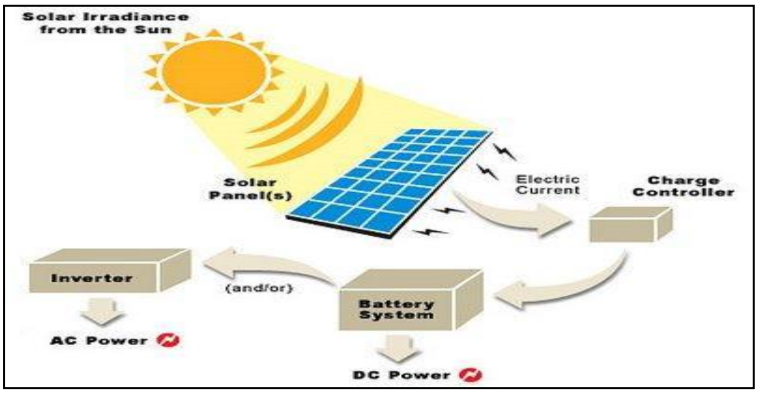

Figure 2.2: A simple PV system

Due to the low voltage of an individual solar cell, several cells are combined into photovoltaic modules (commonly called solar panels), which are then connected together into a photovoltaic array. The electricity generated can be used directly, stored or fed into a large electricity grid. A PVS may also be combined with domestic electricity generators to create a hybrid system.

2.1.3 Terawatt Challenge

15 TW was the mean total world energy power need during 2005. Space based solar power can provide access to yet much more energy. 10kW/person is the mean power (total - electricity, transportation, heating) used in the developed world. The figure 2.3 shows total Surface area required to fuel the world with solar.

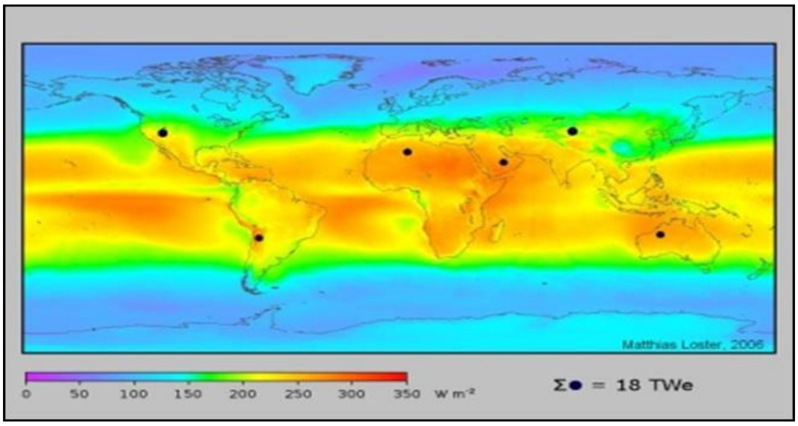

Figure 2.3: Total Surface Area Required to Fuel the World With Solar

Average solar irradiance, watts per square meter. This is for a horizontal surface, whereas solar panels are normally mounted at an angle and receive more energy per unit area. The small black dots show the area of solar panels needed to generate all of the world's energy using 8% efficient photovoltaic.

2.2 Grid Connected System

A grid connected system is connected to a large independent grid (typically the public electricity grid) and feeds power into the grid. Grid connected systems vary in size from residential (2-10kWp) to solar power stations (up to 10s of MWp). In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is met by the PV system. In figure 2.4 a residential grid-connected PV system is shown.

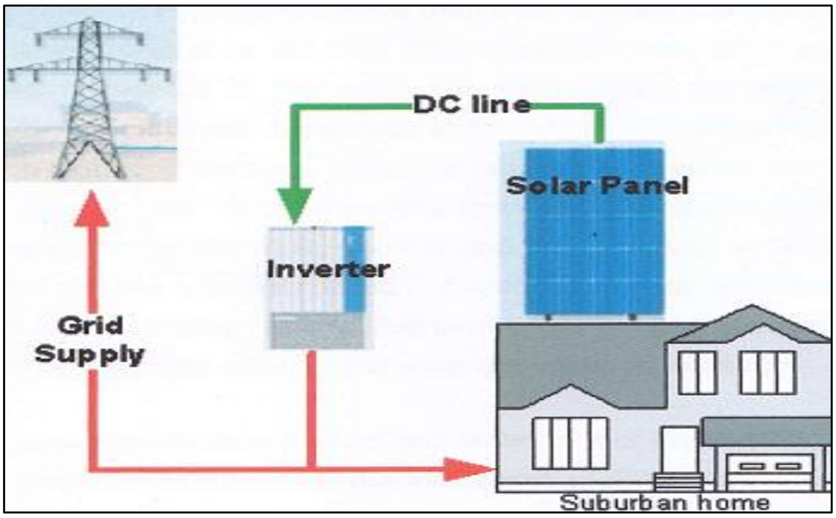

Figure 2.4: A residential grid-connected PV system

Only the excess is fed into the grid when there is an excess. The feeding of electricity into the grid requires the transformation of DC into AC by a special, grid-controlled solar inverter [3].

For two reasons it is a good idea to connect the on grid home power generating system to the grid bi-directionally.

1. It is another revenue source that helps you to cover the capital expense (the utility pays the consumers for electricity they sell to them)

2. In some countries only such systems (bi-directional monitoring grid connected solar) are entitled to tax debates (e.g. California in USA).

That means the consumer gets a bi-directional meter that meters the electricity he buys from the utility (one direction) and the electricity he sells to the utility (the opposite direction). Some utilities pay the same per kWh as the consumer pays them. Some utilities pay more. A good example is Israel. The utility pays 4 times more than what they charge.

Grid-connected PV systems can be subdivided into two kinds:

a. Decentralized grid-connected PV systems,
b. Central grid-connected PV systems.

2.3 Decentralized grid-connected PV systems

Decentralized grid-connected PV systems have generally a small power range and are installed on the roof of buildings (rooftop or flat-roof installation) or integrated into building facades. Energy storage is not necessary in this case. On sunny days, the solar generator provides power, for example for the electrical appliances in the house. Excess energy is supplied to the public grid. During the night and overcast days, the house draws power from grid. The electricity grid acts as a large "storage unit." In the case of a favorable rate-based tariff for PV electricity, it is more feasible to feed all solar electricity into the grid.

For example in Germany around 80% of the more than 50,000 existing grid-connected PV systems are installed either on the roof of a building or integrated into a building facade. The benefit of the installation of a PV system into or onto a building is that no separate area for the solar generator is needed.

The potential for PV power generation on roof and facades is of immense importance. It is the result of a study that was carried out within the framework of lEA-PVPS Task 7.

In figure 2.5 block diagram of the power supply for a house with a decentralized PV system and grid connection has been shown .

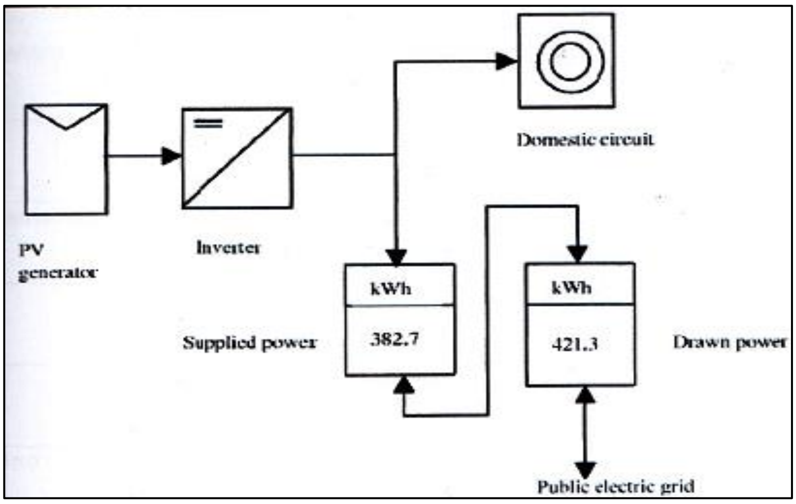

Figure 2.5: Block diagram of the power supply for a house with a decentralized PV system and grid connection

Table 2.1 shows the available areas on roofs and facades offering a good solar yield (80%) as well as the corresponding generation potential in TWh per year.

Table 2.1: Potential PV on roofs and facades for diffrent countries participating in the IEA study. [4]

Country	Building stock area (km^2)		Generation (TWh/y)
Austria	Roof	422.25	68.176
	Facade	185.34	15.881
Canada	Roof	139.62	15.197
	Facade	52.36	3.528
Denmark	Roof	963.54	118.708
	Facade	361.33	33.154

Finland	Roof	87.98	8.710
	Facade	32.99	2.155
Germany	Roof	1295.92	11.763
	Facade	32.99	3.063
Italy	Roof	763.53	128.296
	Facade	286.32	31.745
Japan	Roof	966.	103.077
	Facade	362.39	23.827
The Netherlands	Roof	259.36	117.416
	Facade	97.26	29.456
Spain	Roof	448.82	25.677
	Facade	168.31	6.210

Table 2.2: Amount of electricity consumption in 2000 and percentage of electricity consumption that could potentially be reached with PV on roofs and facades for selected countries [4]

Country	Electricity consumption in 2000 (TWh)	Percentange of PV power generation on roofs and facades
Australia	192.58	43.7
Canada	521.5	29.1
Germany	549.21	29.1
Italy	301.79	42.1
Japan	1057.33	13.9
Spain	209.55	41.3
United Kingdom	358.28	29.4
United States	3812.00	54.6

2.4 Central grid-connected PV systems

Central grid-connected PV systems have an installed power up to the MW range. With such central photovoltaic power stations it is possible to feed directly into the medium or high voltage grid. A PV power station feeds the generated power instantaneously into the utility distribution network (the 'grid') by means of one or more inverters and transformers. The first PV power station was built at Hysperia in southern California in 1982 with nominal power specification 1 MW, using crystalline silicon modules mounted on a 2 axis tracking system. [4]

PV power stations may be approaching economic viability in locations where they assist the local grid during periods of peak demand, and obviate the need to construct a new power station. This is known as peak shaving. It can also be cheaper to place small PV plants within the transmission system rather than to upgrade it.

In figure 2.6 hysperia pv power stations is shown. The photo courtesy is of paul maycock PV energy system[4]

Figure 2.6: Hysperia PV Power Stations[4]

The main advantages of these distributed systems over large PV plants are as follows:

a. The transmission losses are much lower because the load is on the same site as the supply.

b. The value of the PV electricity is also higher because it is equal to the selling price of the grid electricity which has been replaced, rather than to the cost of generating it.

2.5 Smart Grid-Connected Solar Systems: A vision for the future

As the capacity of PV systems and other renewable energy systems is increasing with time, utilities of different countries are using these systems to minimize the cost and environmental impact of fossil fuel-based power generation, to manage peak demands, to provide ancillary services such as spinning reserve, to improve system reliability, and to improve power quality. To accommodate and optimize management of these resources, it is expected that the advanced distribution system will be a "Smart Grid".

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. Smart grids have the potential to improve the efficiency of energy distribution and usage, both through the grids design and through consumer participation.The smart grid allows utility customers to play a bigger role in their power usage, and it encourages them to use power wisely and efficiently. For instance, a customer would be able to log onto a utility's website and track his power usage, learn when rates rise and fall, spot energy drains around his home, and eventually find ways to lower energy consumption. In figure 2.7 components of smart grid are shown .

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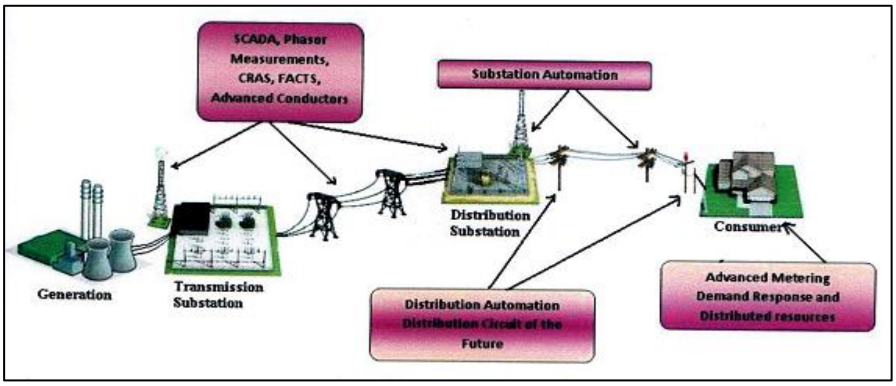


Figure 2.7: Components of Smart Grid

Many smart grid features readily apparent to consumers such as smart meters serve the energy efficiency goal. The approach is to make it possible for energy suppliers to charge variable electric rates so that charges would reflect the large differences in cost of generating electricity during peak or off peak periods. Such capabilities allow load control switches to control large energy consuming devices such as water heaters so that they consume electricity when it is cheaper to produce.

Smart Energy Demand mechanisms and tactics include:

a) Micro grids,
b) Smart meters,
c) Supervisory control and data acquisition(SCADA)system,
d) Modern EMS(energy control system),
e) Flexible Alternating Current Transmission Systems (FACTS),
f) Dynamic pricing,
g) Smart thermostats and smart appliances,
h) Automated control of equipment,
i) Real-time and next day energy information feedback to electricity users,
j) Usage by appliance data,
k) Scheduling and control of loads such as electric vehicle chargers, home area networks (HANS), and others.

Features of the smart distribution system may include but are not limited to:

1. Management of the intermittency of renewable solar resources
2. Automation for power flow and energy management

3.Management of the interface between the utility, distributed resources, and micro- grids

4. Management of all power flow transitions

5. Real time pricing and analysis for the connected community.

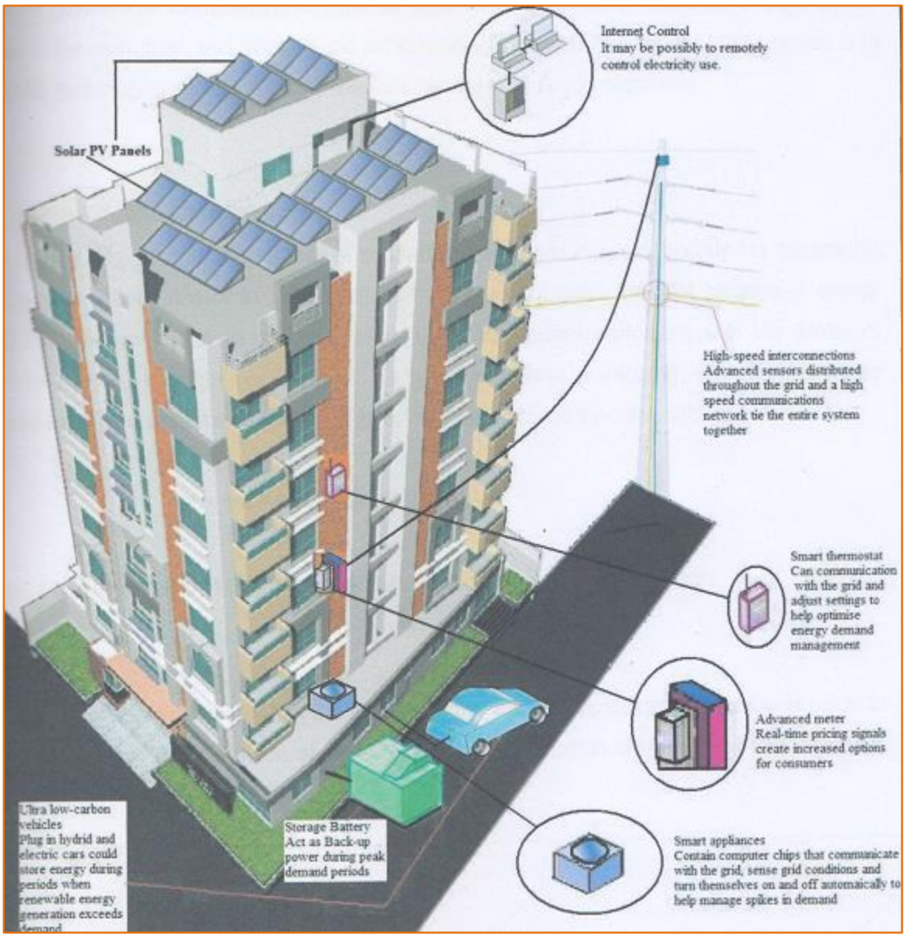


Figure 2.8: A Smart home model [5]

2.6 Geometrical Considerations

PV modules and generators have boundary conditions for their installation and performance e.g. general geometrical Considerations, various possibilities of building integration, large power plants in the open field, and tracking and concentrating systems.

2.6.1 Optical Tilt Angle

The optimal tilt angle for large arrays of south-facing modules is approximately the geographic latitude with a tolerance of ±10 degrees. This arrangement gives the best balance of energy yield over the year. The tilt can also be adjusted for optimal performance in the winter or summer season, by higher or lower tilt. To avoid excessive shadowing, the arrays have to spaced apart by a distance d, given in fig. 2.9 in relation to the module width a

$d/a = \cos\beta + \sin\beta/\tan\varepsilon$

where ε can be expressed by the geographical latitude ϕ and the ecliptic angle

$\delta = 23.5°$, $\varepsilon = 90° - \phi - \delta$

The criterion for this relation is that the shading angle ε of the preceding module row is equal to the sun's azimuth on solar noon at winter solstice. The definition of the angles and distances can be seen in Fig. 2.9

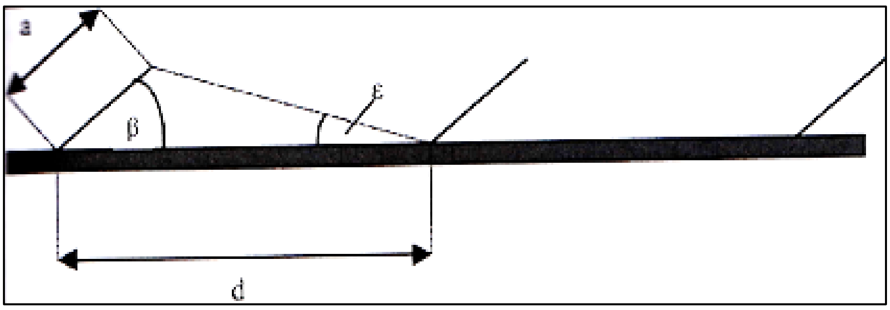


Figure 2.9: Arrangement of a large number of rows of modules [6]

The increase in distance between module arrays with geographic latitude is shown in Fig. 2.10, which is based on Fig. 2.9.

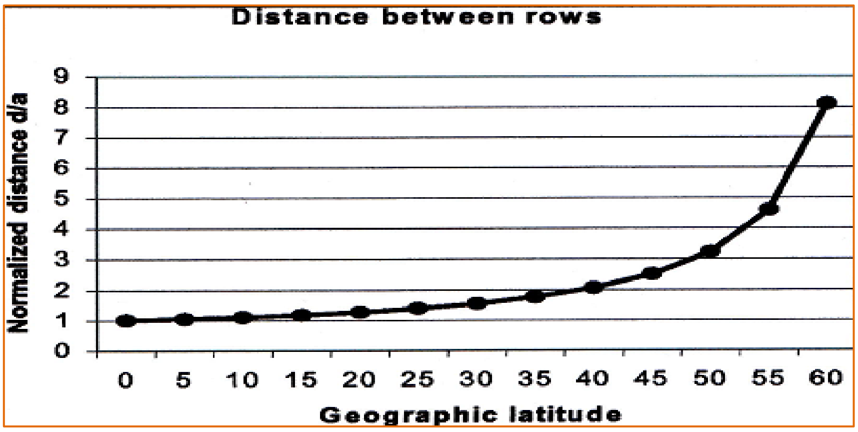


Figure 2.10: Dependence of Normalized Distance Between Rows Verses Geographical Latitude[7]

It can be seen that the area consumed by a PV generator field increases rapidly with increasing latitude and becomes infinity when the Arctic Circle is reached.

2.7 PV Systems In Connection With Buildings

2.7.1 Potentials

The installation of PV systems in connection with buildings has important benefits. No additional areas are necessary because the solar generator can be mounted in or on existing parts of a building such as a roof or facade, the flat roofs are especially suitable for the installation of solar generators. The solar modules can be mounted in optimal orientation and inclination.

By installing solar panels on sloped roofs or on facades, only the south-oriented areas of the buildings can be used. In addition, for each of the installation concepts, the possible shading, e.g., by trees or neighboring buildings must be considered. In spite of these restrictions, the potential for PV power generation on roof and facades is considerable.

Between 1985 and 1995 grid-connected PV systems were installed in great numbers for the first time on buildings in many countries. At this time, some countries started extensive programs for demonstrating and testing the grid connected PV technology. One of the aims was to prove that PV systems can be installed and operated without any problems in existing or newly erected buildings. Also, within these programs the components of grid connected PV systems, especially the solar modules and the inverters, could be tested in greater numbers under realistic operating conditions. As a result, these components were greatly improved [8].

While at first single solutions dominated for nearly each building, now numerous technically proven standard solutions are available. Mostly, the PV systems were installed on the roof of single family houses. In Europe, such houses do not have more area with good orientation and inclination. PV systems that are integrated into building facades often have higher power because the usable areas are larger.

The installation or integration possibilities of a solar generator in buildings can be subdivided by building surface or type of installation:

a) **By building surface**

i. Installation on a flat roof
ii. Installation on a sloped roof
iii. Installation on a facade

b) **By type of installation**

i. Mounted on racks (e.g, on flat roofs)
ii. Integrated into the roof or façade, in this case, the generator replaces part of the building envelope
iii. Mounted at a distance of several cm above the building surface (for better cooling of the modules)

C) **Other possibilities of integration such as sun shades**

All these alternatives have their own boundary conditions influencing systems technology and performance, which will now be described.

2.7.2 Installation on the roof

The installation possibilities for a solar generator on the roof of a building depend on the type of roof, i.e., a sloped or flat.

Installation on a Sloped Roof

By using of specific — today mostly standardized — supports, the modules are installed at a distance of around 5 cm from the existing roof tiles [9]. In figure 2.11, an example of an installation on a slope roof is shown.

Figure 2.11: Example of an installation on a slope roof [6]

Installation on a Flat Roof

The solar modules comprising the solar generator are mounted on a support structure on the surface of the flat roof. Mounting frames available on the market today have high stability. They also do not violate the integrity of the roof of the structure, and in most cases it is also not necessary to puncture the roof for the cable connection between the solar generator and the inverters because the inverter can be located directly underneath the solar modules. The inverters should be housed in a weather-proof container. The installation of the inverter directly on the flat roof has the additional advantage that the cable connection between solar generator and inverter is very short. This is important because the handling of large dc currents presents many safety problems in connection with arcing. Another advantage of the installation of a solar generator on a flat roof is that it is possible to optimally mount the solar modules in orientation and inclination.

Figure 2.12: Example of an Installation on a Flat Roof

2.7.3 Roof-integrated systems

There are two main possibilities of integration into a sloped roof. Solar modules replace part or all of the normal roofing material. In this case the solar modules have a double function. They perform the function of a roof and, in addition, produce electric energy. In figure 2.13 roof-integrated systems is shown. It is also possible to use special solar roof tiles. These are modules of only a few Wp that are shaped like a regular roof tile.

Figure 2.13: Thyssen-Solartec_r Solar Modules [10]

The main advantage of the solar roof tiles is that integration in a conventional roof is possible without problems. The disadvantage of the solar roof tiles is the very high expense for the connection of the great number of solar tiles to one solar generator.

2.7.4 Facade-integrated systems

Facade-integrated solar generators do not have the optimal orientation and inclination. They are practically always vertical. The loss in power output depends on geographic latitude.

Figure 2.14: The PV Façade at the Office Building of the Fraunhofer ISE ,Freiburg[7]

Assuming a southern orientation of the facade, output increases the further north (or south on the southern hemisphere) the building is located. In Central Europe, a vertical module delivers about 70% of the yearly energy of an optimally oriented module .The construction of an optically demanding building facade can be combined with an innovative environmentally beneficial power generation. power generation. Especially banks, administrations, and environmental organizations have installed facade-integrated PV systems (Figs. 2.14 and 2.15).

Figure2.15: PV facade of the Solar Office at Doxford International,Suderland,U.K.[7]

2.8 Important Parameters

The main purpose of a grid connected PV system is to generate an optimal amount of electric energy over a given time, usually one year. This amount depends on the irradiation at the location in which the PV system is operating and on the quality of the components used. The performance of a PV system can be estimated by obtaining certain parameters e.g. Final yield, Performance ratio, control of quality and energy yield etc.

2.8.1 Final yield

For grid-connected PV systems the energy yield (E_{USE}) measured by a separate AC meter at the inverter exit is basic for all further considerations. Its dimension is kWh. To have the possibility to compare different PV systems at the same operating location, the energy yield is divided by the nominal power (P) of the solar generator (kWp), which is given in the data sheet for the solar module. In order to obtain the nominal power of the generator, the number of modules of the generator has to be multiplied by the nominal power of a single module. The result is the standardized yield or, better, the final yield (Y_F):

$Y_F = E_{USE} / P_N$ (kWh/kWp)

where:

E_{USE} = energy yield measured by a separate AC meter

P_N = nominal power of the solar generator.

2.8.2 Performance ratio

The performance ratio allows comparison of PV systems at different operation locations. It is defined by the following relation:

$PR=100\times[E_{USE}/(\eta STC \times ES)]$ %

ηSTC= efficiency of solar modules under Standard Test Condition (STC)

ES= irradiation at the solar module area during the considered time [kWh/m^2]

Or simplified

$PR= Y_F /Y_R$

Y_F =final yield [kWh/kWp]

Y_R = irradiation at solar module area during the considered time [kWh/m^2] divided by the irradiation under STC (1,000/ m^2)

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.

Figure 2.16 shows the development of the PR in Germany during 1993 to 2002. The number of PV plants in each reported year is variable. For example, in 1994 more than fifty PV plants were involved, and in 2002 less than ten. Fig. 2.16 shows a slowly increasing performance ratio from 1994 to 2002. There is a wide fluctuation in the maximum PR between the individual PV systems , from less than 60% up to nearly 90%.

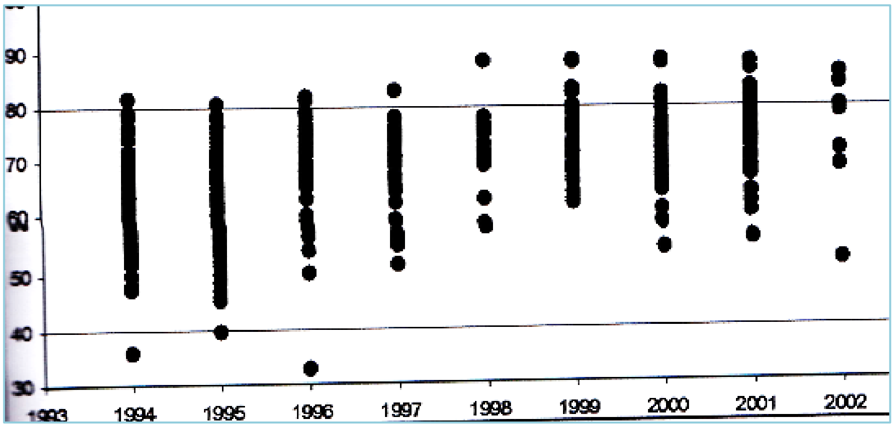


Figure 2.16: Development of the performance ratio for grid-connected PV systems in Germany [11].

The following reasons, among others, can be given for those differences:

i. Bad quality of the installation of PV systems ,for example, the area of the solar generator is temporarily or partially shadowed, especially during times with high irradiation.
ii. The components of the PV system are of bad quality;
iii. Problems with the inverter efficiency
iv. Problems with the operation of the PV systems; most often reported are defects and downtime of inverters.

Table 2.3: The Average performance ratio for grd-connected PV system in some selected countries [6]

Country	1994	1995	1996	1997	1998	2000	2001	2002
Germany	65	64.9	68	69	73.7	71.9	73.3	73.4
Italy*	58	48.2	58.1	55.6	58.6	67.6	68.6	74.5
Japan	....	74	76	70	70	71	69	67
Switzerland I**	69	69	68	56	63	72	...	...
Switzerland II***	69	69	68	71	69	68	63	...
Switzerland III***	...	...	66	72	70	68	66	...

*** Average annual**

**** PV systems installed 1989-1992**

***** PV Systems installed 1995-2000**

Table 2.4: Annual final energy yields in different counties for comparison [6]

Contry	**Number Range of systems analyzed**	**Range of final yield (KWh/KWp)**	**Average final yield (KWh/KWp)**
The Netherlands	10	400-900	700
Germany	88	400-1030	700
Switzerland	51	450-1400	790
Italy	7	450-1250	864

Japan	85	490-1230	990
Israel	7	740-2010	1470

2.8.3 Possibilities of quality control and control of energy yield of grid-connected PV Systems

As some countries have adopted feed-in tariffs for grid-connected PV systems, control of the quality and energy yield have become more important than before, especially for PV systems with greater power. In view of this, some companies and engineering consultants offer different methods for the continuous supervision of PV systems. To assess the efficiency of a PV system. Only two measured data are necessary:

a) The irradiation in the solar generator area and

b) The energy yield (Euse) measured at the AC level at the inverter exit

To measure the irradiation in the solar generator area usually a special silicon sensor is used. With these two data and the technical description of the individual PV systems it is possible to calculate the final yield and the performance ratio .

At present, low-priced data loggers are available on the market. The data logger collects the two above mentioned data and also some others like module temperature, ambient temperature, solar generator output (DC), and wind velocity. The data are transmitted to an evaluation computer via telephone connection. Also, transmission by Internet is possible. For a low-power PV system (maximum up to 5 kWp) a monthly reading of the electricity meter (DC) of the PV system is enough. Then, the data can be sent for evaluation to a company or an engineering office offering such service, or the owner can evaluate the data himself. For this purpose some companies are offering low-price control units that enable the layman to identify disturbances of the PV system or its components. Especially manufacturers of inverters and data loggers are active in this direction.Another possibility for evaluation of a PV system is quality control and control of the energy yield by using satellite data. The EU JOULE Ill project PVSAT has set up a remote performance check for grid-connected PV systems. No additional hardware installation is necessary on site. The site-specific solar irradiation data are derived from satellite images rather than from ground based measurements [12].

A target yield is estimated for each individual PV system on a monthly basis. It is reported to the system operators to allow a comparison between targeted and real yield values.

The PVSAT procedure is based on three main components:

1. a database of PV systems configuration data,
2. a satellite image processor, and
3. a generic PV system model.

These data are to be collected once for each participating system. The continuous reception and processing of METEOSAT images allows for the production of site-specific time series of solar irradiation data for each of the locations. For Mid-European countries, METEOSAT images offer a resolution of 2.5x4.5 km^2. They are available in 30-minute intervals. In consecutive steps, the irradiation on a horizontal plane is converted to the tilted plane irradiation and any local horizon obstruction is taken into account. In figure 2.17 Schematic View of the PVSAT Scheme is shown .

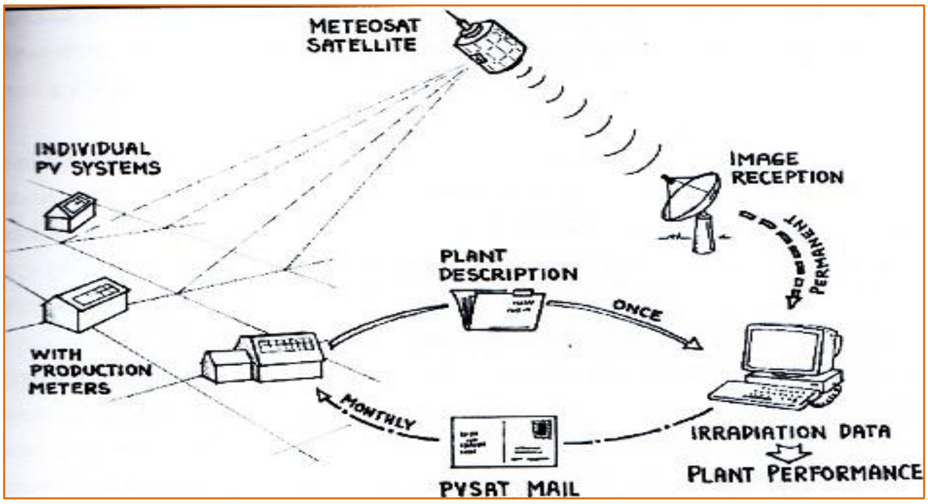


Figure 2.17: Schematic View of the PVSAT Scheme [11]

At the end of each month, individual yield values are calculated for all PV systems. For this purpose, a generic system model is fed with the configuration data and corresponding irradiation time series. The results of the model calculation are transferred back to the database, from where they are distributed (mailed, faxed , or e-mailed) to the individual system operator. He or she may then compare the estimated production to the real production meter reading.

Also possible for control of PV systems is the combination of data received from METEOSAT with meteorological data collected from a closely meshed grid of meteorological offices. As mentioned above the information about the results of the control can be given by SMS, e-mail, or phone.

2.9 Long-Term Behavior Of Grid-Connected PV Systems

Up to the present, only a few studies or analysis dealing with the long-term behavior of grid- connected PV systems had been carried out. Most of them involved only a small number of PV systems or the time period for which the analysis was carried out was relatively short, mostly not more than five to ten years. Nevertheless, in the following, a short overview of the long-term behavior of the main components of a PV system will be given.

2.9.1 Solar module

All known reports and studies about the performance of PV systems came to the conclusion that the solar module is the most reliable component of the PV system. At present, most of the manufacturers give a lifetime guarantee of twenty to twenty-five years for the modules. They guarantee a power of 80% of the nominal power after that time. The observations of the performance of modules reported here are not limited to modules in grid-connected systems. Practically all data, however, were obtained from grid-connected systems. The reasons for the few reported failures of PV systems due to the modules can be traced to failure in the module production process related to insufficient quality assurance by the solar module manufacturer such as delaminating or failing solder contacts.

Degradation of photovoltaic modules follows a progression that is dependent on multiple factors. Information on module degradation has been collected since the early 1970s. So, for example, module performance losses of 1-2% per year were found in systems tested over a ten year period. Data from a multicrystalline module continuously exposed outdoors in open circuit configuration for eight years show about 0.5% per year performance loss. [7]

A statistical comparison of 191 individual module parameters at normal operating cell temperature (NOCT) shows as a result the decrease in Pmax from 39.88W to 38.13 W. This represents a 4.39% drop in the average maximum power produced by individual modules during the eleven years they have been in operation [6]. The database for the reported performance losses is very small. In addition, different measurement techniques and analytic methods were used. Therefore, the obtained results often are not comparable with each other.

The observed degradations, which may take up to five years before becoming evidentiary, are given below:

i. Degradation of Packaging Materials
ii. Loss of Adhesion (the breakdown of the bonds between materials layers that constitute a module laminate.)
iii. Degradation of Cell/Module Interconnects
iv. Degradation Caused by Moisture Intrusion
v. Degradation of the Semiconductor Device
vi. Degradation Due to Dirt and Dust on the Module Surface

2.9.2 Inverter

The inverter is a piece of electronic equipment like many others. Failures that are customary in such equipment can occur also in the inverter.

Some examples are given in the following:

i. Defective safety fuses
ii. Breakdown of an electronic component
iii. Overheating causing faulty operation of the inverter
iv. Overvoltage effect on the inverter

All modern inverters have an integrated overvoltage protector, but in some cases such as lightning in the direct neighborhood of a PV system can cause an overvoltage to appear at the inverter. Studies of the long-term behavior of PV systems have shown that the inverter is the most frequent reason for failure of the complete system. More than 60% of all identified interruptions of PV systems are caused by the inverter [7].

2.9.3 Mounting racks and fixing materials

The only long-term problem caused by mounting racks and fixing materials is normal corrosion. For the selection of the material used for mounting racks and fixing devices, the electrochemical contact voltage has to be taken into account. If is this not done, a rapid corrosion of the less noble metal will occur.

2.9.4 Cables

Normally the cables used for PV systems have the same long-term stability as cables that are used for other purposes, but because the cables in PV system are partly outdoors, the material should be resistant to UV radiation. Additionally, the cable must be resistant to mechanical strain, e.g., shearing of the cable cover.

A special problem has been reported in some cases in Germany. It has been observed that martens have a special liking for the plastic sheets of the cables of PV systems. The martens sometimes interrupt the connection of the generator with the inverter. The consequence is a total breakdown of the PV system. Maybe this problem occurs in other Central European countries as well.

2.10 Electric Safety Of Grid-Connected PV Systems

An important factor for the large-scale introduction of PV systems is the observance of the legal regulation of the electric safety of these systems. If the regulation or standards are not observed by the installer or during the operation of the PV systems, failures or interruptions can result.

The electrical safety of grid-connected PV systems is mostly regulated by national or international standards. An example is the international standard IEC 364, Electrical Installations of Building (IEC = International Electro technical Commission), which regulates electrical installations of buildings. This standard is accepted by many countries. The IEC 364 contains, among other things, requirements to protect against dangerous body currents, protection against short circuit and overload, recommendations for the selection and installation of cables and wires, and recommendations for overvoltage protection [12].

As mentioned already, there is not a single standardized regulation for the electric safety of PV systems that is generally binding. For the installation of grid-connected PV systems, the national and international standards which apply in the concerned country must be observed. Some universally accepted recommendations for materials to be used for the installation of PV systems are given below:

PV Modules

In addition to the established standard specifications for PV modules, the following parameters should also be stated in the data sheets:

i. Protection class,
ii. Maximum permissible system voltage (Voc at STC),
iii. Maximum permissible current in reverse direction.

Cables and Cable Installation

Installation of PV systems presents unique problems, because it is a DC system. This presents a challenge to the installers, who are almost exclusively used to AC systems. The danger of arcing is much greater even at relatively low voltage.

The selection of cable type and cable size depends strongly on the installation method and the expected maximum ambient temperature. In Central Europe, air temperatures close to the roof may reach up to 70ºC, therefore, cables should be rated for at least 80°ambient temperature.

Material used for the insulation of these cables and wires should be rated self-extinguishing; if they are laid openly, they also have to be resistant to UV radiation and weathering. To eliminate the risk of ground faults and short circuits, the installation should be done in a “ground fault and short-circuit proof ” way. This requirement usually means laying separate wires for plus and minus (and a possible center tap conductor) either by using single insulated wires in separate cable ducts or doubly insulated cable, type HO7RN-F, or a cable type of similar quality. In systems with a higher risk of lightning strike, these two cables should be placed close to each other to reduce coupling of overvoltage from nearby lightning strikes. If a high risk of lightning strikes does exist, it is recommended to place the cables into metallic cable trunks that are grounded at least on either side. All string cables should be marked for string identification and standard colors for "+" and "—" [11].

Terminals and Junction Boxes

Due to their large number, junction boxes of modules are a likely location to develop an arc due to a failing connection. Therefore, junction boxes and terminals inside junction boxes should be nonflammable. The generator junction box has to be included in the protective measure. It should be made from plastic, because this eases the ground fault and short-circuit proof installation. Where no grounded metallic case is present, no ground fault to it can develop. The requirement for ground fault proof and short-circuit proof installation also affects the arrangement of wires in the junction box. Internal wiring must also use doubly insulated cable, plus and minus sections should be spatially separated or physically separated by an insulating barrier. All in and outgoing wires shall be mechanically secured, e.g., by cable glands. This ensures that even if a terminal loosens and a wire can leave the terminal, it will be technically held in place and unable to contact another metal part.

Switch gear and Fuses

Between the PV generator and inverter a circuit breaker should be installed such that the PV generator output can be disabled if maintenance work on the inverter has to be done. All switchgear on the DC side like circuit breakers, disconnection terminals, fuses, etc. must be rated for direct current under the full open circuit voltage (at STC) of the PV generator. Failing switches have caused several incidents in the first European PV pilot plants using voltages higher than 200 V.

Fuses should be rated for at least 130% of the respective nominal branch current to allow for periods of increased irradiance. If higher temperatures are to be encountered, e.g., in an attic or in an outdoor junction box, fuses must be derated. An operating temperature of 60º requires a 20% derating compared to the value at 20°C [7].

CHAPTBR 3

BIOGAS: IT'S APPLICATION IN HOME SYSTEM

3.1 Introduction of biogas

The technology for the production of biogas, by anaerobic fermentation of organic materials which are abundant, low-cost and renewable in nature, is readily available. In fact, several thousand biogas plants are already in operation in many developing countries such as India, China, Thailand, Asian countries and others.

However, further widespread generation and use of biogas depend largely on the availability of inexpensive and appropriate plant designs, which could be constructed with locally available materials and skills. Also, it is important that financial institutions and national governments consider liberal fiscal incentives to make this technology attractive at the level of individual families as well as communities.

The thesis explains the theory of biogas productions, factors affecting plant designs, and operation of plants. Details of several popular biogas plant designs, their construction, installation, operation and maintenance have been covered with appropriate illustrations. Designs of biogas utilization devices and their operational requirements for used in lighting and cooking and as fuel for prime movers have also been included. Further, the use of digested slurry as a source of organic fertilizer is discussed. Technical problems faced in the construction and operation of biogas plants and appliances have been identified along with the causes .

3.1.1 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, twigs grasses, industrial waste, etc. The presence of methane in biogas lends it the property of combustion which makes it suitable for cooking, lighting, and powering prime movers.

Mechanism of extraction :

The fermentation process for formation of methane from cellulosic material through the agency of a group of organisms belonging to the family "Methanol bacteriaceae" is a complex biological and chemical process involving two main stages.

First Stage: bacteria break down into complex organic materials, such as carbohydrates and chain molecules, fruit acid material, protein and fats. The disintegration produces acetic acid, lactic acid, propaonic acid, butanoic acid, methanol, ethanol and butanol, carbon dioxide,H_2S and other non organic materials, in this stage the chief micro-organisms are ones that break down polymers, fats, proteins and fruit acids, and the main action is the butanoic fermentation of polymers.

Second Stage: the simple organic materials and carbon dioxides that have been produced are either oxidized or reduced to methane by micro-organisms of which there are many varieties.

3.1.2 Methane production:

Airtightnees : breakdown of organic materials in the presence of oxygen produces CO_2 and in the absence of it produces methane.

Temperature: Temperature for fermentation will greatly affect biogas production. Depending on prevailing conditions methane can be produced within a fairly wide range of temperature. However, the micro-organisms which take part in methane fermentation have the optimum activity at 35ºC – 40ºC. The production of biogas is fastest during summer and it decreases at lower temperature during winter. Also methanogenic micro-organism are very sensitive to temperature changes, a sudden change exceeding 30ºC will affect production, therefore one must ensure relative stability of temperature.

This stage may be represented by the following overall reaction:

$$(C_6H_{10}O_5)_n + H_2O \longrightarrow 3nCH_4 + 3nCO_2$$

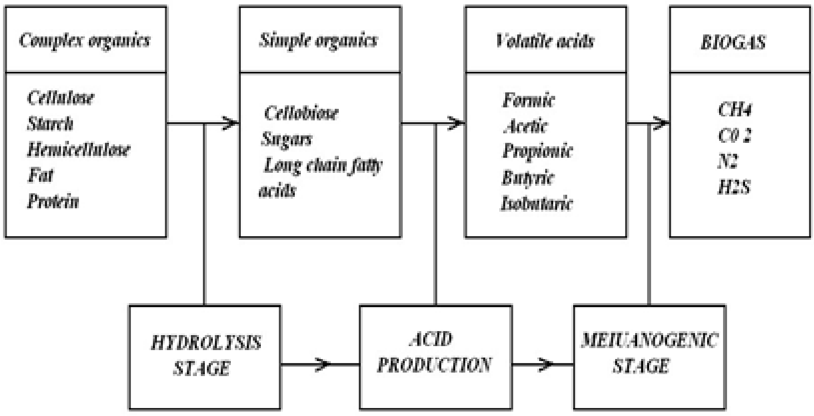


Figure 3.1: Pathway for Anaerobic Decomposition

Individual reaction include:

1. Acid breakdown into methane

$$2C_3H_7COOH + H_2O \longrightarrow 5CH_4 + 3CO_2$$

2. Oxidation of ethanol by CO_2 to produce methane and acetic acid.

$$2C_3\,CH_2\,OH + CO_2 \longrightarrow 2CH_3COOH + CH_4$$

3. Reduction with hydrogen of carbon dioxide to produce methane

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2\,O$$

A careful balance should be maintained between the two stages. If the first stage proceeds at a much higher rate than the second, acid will accumulate and inhibit the fermentation in the second stage, slow it down and actually stop it.

pH factor: The micro-organisms require a neutral or mildly alkaline environment ,a too acidic or too alkaline environment will be detrimental. Ideal pH value is between 7.0 – 8.0 but can go up or down by a further 0.5. The pH value depends on the ratio of acidity and alkalinity and the carbon dioxide content in the biogas digester, the determining factor being the density of the acids. For the normal process of fermentation, the concentration of volatile acid measured by acetic acid should be below 2000 parts per million ,too high a concentration will greatly inhibit the action of the methane.

Solid contents: Suitable solid contents of raw materials are between 7-9%. Dilution should be in the ratio of 4:5 or in equal proportion.

C/N ration: A specific ration of carbon to nitrogen must be maintained between 25:1 and 30:1. The ratio varies for different raw materials.

Water content: This should be about 90% of the weight of the total contents. With too much water the rate of production per unit volume in the pit will fall, preventing optimum use of the digester. If the water content is too low, acetic acid will accumulate, inhibiting the fermentation process and hence production and also thick scum will be formed on the surface. The water content differs according to the raw material used for fermentation.

Nature of organic materials: materials rich in cellulose and hemi-cellulose with sufficient protenaceous substance produce more gas. Complex polysaccharides are more favorable for methane formation while only protenacous materials produce little quantity of gas. Lignin as such does not contribute to the gas production.

Supplementary nutrients: In case of cow dung, as it contains all the nutrients needed by organisms for the production of methane there is no necessity for addition of nutrients to it.

Reaction period: Under optimum condition 80-90% of total gas production is obtained within a period of 3-4 weeks. Size of the fermentation tank also decides the reaction period.

Harmful materials: The micro-organism that help to produce biogas are easily affected by many harmful materials. Maximum allowable concentration of such harmful materials is as follows:

Sulphate (SO_4^-)	5000 parts per million
Sodium chloride (NaCl)	40,000 parts per million
Copper (Cu)	100 mg per liter
Chromium (Cr)	200 mg per liter
Nickel (Ni)	200-500 mg per liter
Cyanide (CN^-)	below 25 mg per liter
ABS (detergent compound)	20-40 parts per million
Ammonia (NH_3)	1,500-3,000 mg per liter
Sodium (Na)	3,500-5,500 mg per liter
Potassium (K)	2,500-4,500 mg per liter
Calcium (Ca)	2,500 – 4,500 mg per liter
Magnesium (Mg)	1,000 – 1,500 mg per liter

These toxic material should either not be present or their concentration should be diluted, for example by addition of water.

3.2 Effectiveness of Renewable Energy Based Home Energy System In Bangladesh

The renewable energy resources in Bangladesh are the solar, biogas, wind, hydro and tidal energy. Tidal energy conversion technology is still not cost effective for Bangladesh. Offshore wind farm is not suitable for Bangladesh because the wind speed is too small in most of places of Bangladesh. Although onshore wind farm is suitable for some of the areas, but wind is not considered too much available resources in Bangladesh. Another renewable energy source of Bangladesh is the small hydro. Small hydro is suitable for some selective spots. The most available and useful renewable resources of Bangladesh are solar and biogas. These two resources are available throughout the country. Electricity generation from biogas is cost effective in Bangladesh. But cost of electricity from photovoltaic cell is still too much high. But the combination of solar and biogas for electricity generation increase the system reliability and also decreases the cost. Where the biogas resource is not too much available solar-biogas hybrid system is cost effective there. But this hybrid system will not be cost effective for the areas that contain available biogas resources.

3.3 System Overview

The system to be designed is similar to a small power plant. The system may be designed with single source only or more than one source together as hybrid but the focus is given to cost reduction. Considering the cost, the biogas source is selected as primary source for the proposed system. Poultry farms facilitate the waste for biogas generation in this system. The system block diagram is shown in figure 3.2.

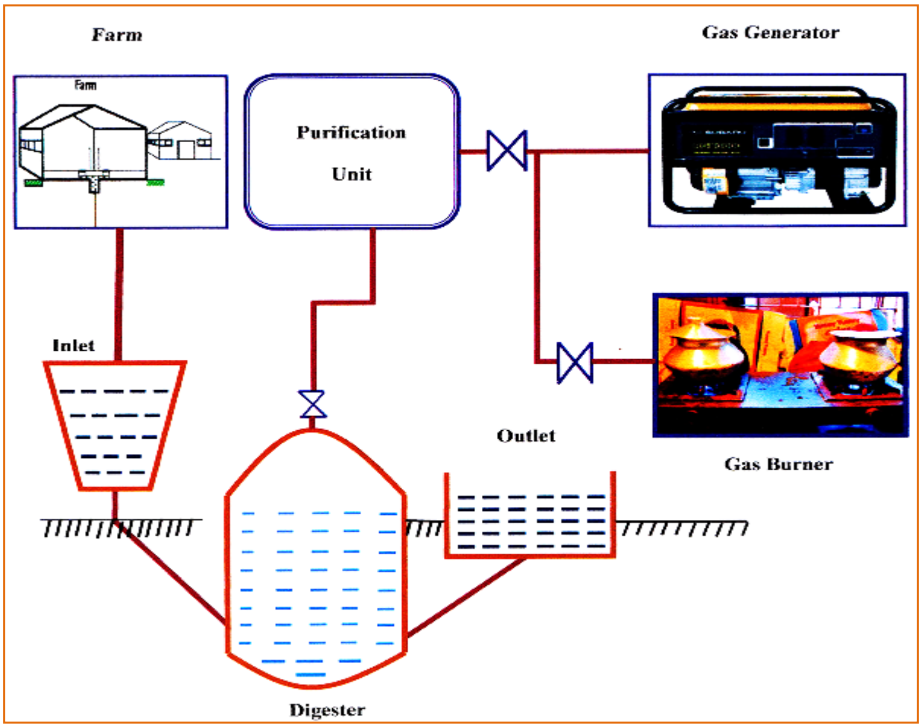


Figure 3.2: Block Diagram of the Designed Energy Home System

3.4 Components and Operation Of Designed Renewable Energy Based Home System

The components can be classified into two types:

1. Components for biogas based electricity generation.

   a. Receiving tank/ inlet.
   b. Digester.
   c. Outlet.
   d. Gas purification unit
   e. Gas generator.
   f. Biogas burner

2. Control circuit, transmission line and other associate components.

3.5 Components For Biogas

i. **Receiving Tank/ Inlet**:

The waste is first taken to the receiver and mixed-up with water to make the favorable total solid (TS) value of the waste. The waste is then sent to the digester.

ii. **Digester**:

Digester is the main part of a biogas plant. The process of gas generation, called fermentation process occurs in the digester. The design of the digester should be such that no air can enter into the digester. The generated gas in the digester gather in the upper part of the digester called gas collected chamber.

iii. **Outlet**:

Due to the pressure of gas in the gas collection chamber some of waste goes out from the digester every day. They exit through the outlet

iv. **Gas Purification Unit**:

Biogas produced from poultry waste contains 60-65% methane. It also contains carbon di-oxide, hydrogen sulfide and some other impurities. These impurities affect the generator combustion process. The main purpose of the gas purification unit is to remove mainly the moisture and hydrogen sulfide.

v. Gas Generator:

Gas generators are internal combustion gas engine. They internally burn the biogas and convert the chemical of the biogas to mechanical rotation which further converted into electrical energy.

vi. Biogas Burner:

The biogas burners are special type of burners whose design is basically different from normal gas burner. By burning the biogas the biogas burners help in the purpose of cooking.

3.6 Control Circuit, Transmission Line and Other Associate Parts

The electricity will be supplied from the generator. The function of the control circuit is to switch the transmission system from biogas plant to the grid. This can be simply done by a manually operated circuit breaker.

In small hybrid system, power will be transmitted within a short distance. So transformer is not required for transmission and distribution purpose. Also protection of the transmission line is not required. Only simple wire is enough for transmission and distribution.

The other associate parts such as pipe line special SS ball valves, electrical energy (kWh) meter (digital), manometer etc. are also used in the system for supplying the gas to the proper place, recording the electricity uses, monitoring the gas pressure.

3.7 Origin of Biogas

Biogas originates from bacteria in the process of bio-degradation of organic material under anaerobic (without air) conditions. The natural generation of biogas is an important part of the biogeochemical carbon cycle. Methanogens (methane producing bacteria) are the last link in a chain of micro-organisms which degrade organic material and return the decomposition products to the environment. In this process biogas is generated, a source of renewable energy [13].

3.8 Substrate and Material Balance of Biogas Production

In principle, all organic materials can ferment or be digested. However, only homogenous and liquid substrates can be considered for simple biogas plants: faeces and urine from cattle, pigs and possibly from poultry and the wastewater from toilets. When the plant filled, the excrement has to be diluted with about the same quantity of liquid, if possible, the urine should be used. Waste and wastewater from food-processing industries are only suitable for simple plants if they are homogenous and in liquid form. The maximum of gas-production from a given amount of raw material depends on the type of substrate [13].

3.9 Composition and Properties Of biogas

Compositions of biogas produced in anaerobic biogas reactors and at a landfill are shown in table 3.1 and table 3.2.

Table-3.1: Average composition of reactor biogas. [14]

Matter	%
Methane , CH_4	55-65
Carbon dioxide , CO_2	35-45
Nitrogen, N_2	0-3

Hydrogen, H_2	0-1
Hydrogen sulfide ,H_2S	0-1

Table-3.2: Average composition of biogas recovered at a landfill (landfill biogas) [15]

Methane	Content
Methane , CH_4	50
Carbon dioxide , CO_2	45
Oxygen, O_2	0.8
Nitrogen, N_2	5
Hydrogen sulfide ,H_2S	21 mg/m^3
Halides	132 mg/m^3
NMOC's (non methane organic compounds)	2700 mg/m^3

Total solid is a very important factor for optimum biogas production. Some solid contents are given in next page. The purpose of practical use CH_4 content is very important which can be analyzed by using digital gas analyzer.

Table-3.3: The total solid content of common fermentation materials in rural areas (approximately) [16].

Materials	Dry matter content(%)	Water content (%)
Dry rice straw	83	17
Dry wheat straw	82	18
Corn stalks	80	20
Green grass	24	76
Human excrement	20	80
Pig excrement	18	82
Cattle excrement	17	83
Human urine	0.4	99.6
Pig urine	0.4	99.6
Cattle urine	0.6	99.4

Table-3.4: Biogas production rates of some fermentation materials and their main Component- [16]

Materials and their main components	Yield of biogas m^3 /kg TS	Methane content (%)
Animal barnyard manure	0.260 ~ 0.280	50-60
Pig manure	0.561	0
Horse droppings	0.200 ~ 0.300	0
Green grass	0.630	70
Flax straw	0.359	0
Wheat straw	0.432	59
Leaves	0.210 ~ 0.294	58
Sludge	0.640	50
Protein	0.980	50

3.10 The Steps of Biogas Production

Biogas microbes consist of a large group of complex and differently acting microbe species, notable the methane-producing bacteria. The whole biogas-process can be divided into three steps: hydrolysis, acidification, and methane formation. Three types of bacteria are involved [17].

1) **Hydrolysis**

In the first step (hydrolysis), the organic matter is enzymolyzed externally by extracellular enzymes (cellulose, amylase, protease and lipase) of microorganisms. Bacteria decompose the long chains of the complex carbohydrates, proteins and lipids into shorter parts..

2) **Acidification**

Acid-producing bacteria, involved in the second step, convert the intermediates of fermenting bacteria into acetic acid (CH3COOH), hydrogen (H2) and carbon dioxide (CO_2). These bacteria are facultative .anaerobic and can grow under acid conditions. To produce acetic acid, they need oxygen and carbon. For this, they use the oxygen solved in the solution or bounded-oxygen. Hereby, the acid-producing bacteria create an anaerobic condition which is essential for the methane producing microorganisms.

3) Methane Formation

Methane-producing bacteria, involved in the third step, decompose compounds with a low molecular weight. For example, they utilize hydrogen, carbon dioxide and acetic acid to form methane and carbon dioxide. Under natural conditions, methane producing microorganisms occur to the extent that anaerobic conditions are provided, e.g. under water (for example in marine sediments), in ruminant stomachs and in marshes. They are obligatory anaerobic and very sensitive to environmental changes.

A simplified generic chemical equation for the overall processes outlined above is as follows:

$$C_6\,H_{12}\,O_6 \rightarrow 3CO_2 + 3CH_4$$

The block diagram of anaerobic fermentation process is shown in figure 3.3 & 3.4

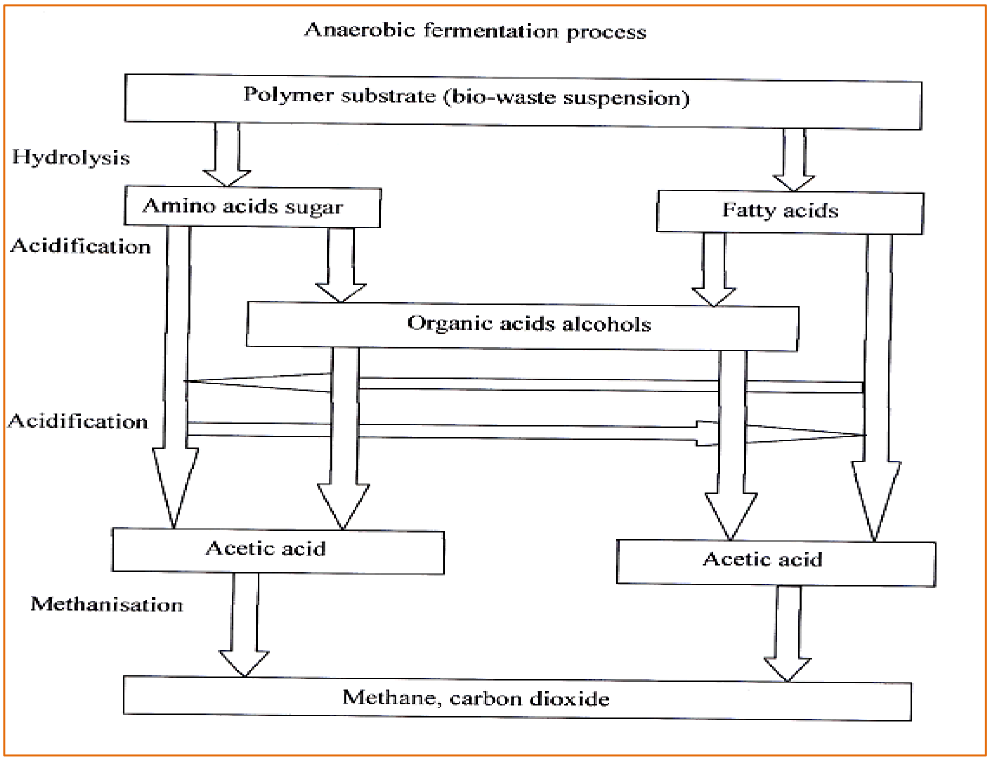


Figure-3.3: Block diagram of anaerobic fermentation process

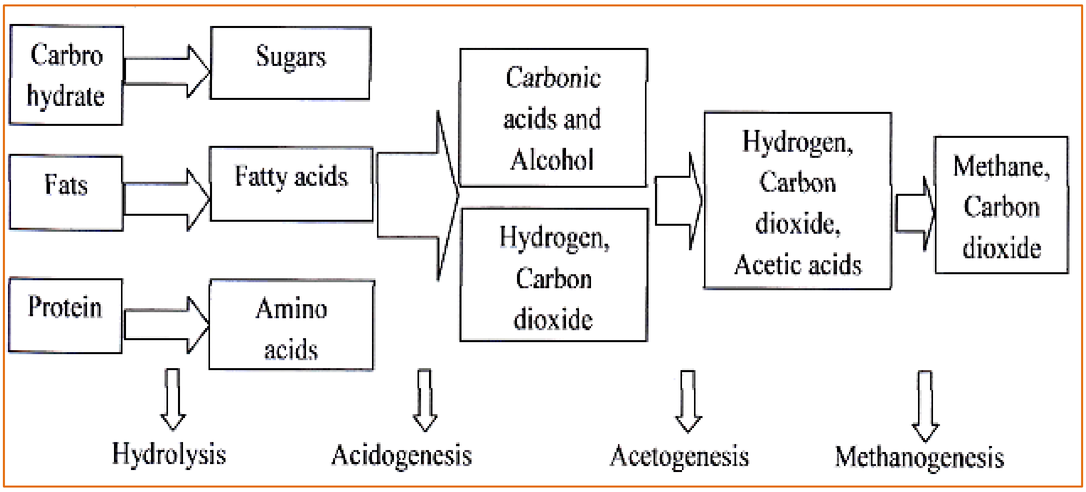


Figure 3.4: Block diagram of anaerobic fermentation process

CHAPTER 4

SYSTEM ARRANGEMENT OF SOLAR PANELS

4.1 Site Area Calculation

The area available for installing the solar system has been calculated as follows:

The total rooftop area of a typical 6 storied building is 6370 sft.

The area of the stair room+ machine room + meeting room = 450 sft.

Void area =125 sft.

Parapet wall=110 sft.

Available open space for solar system = 6370 -450 - 125 - 110 = 5685 sft

Loss area = 5% of the available open space = 285 sft.

So the area can be used for installing solar panel = 5685 -285 = 5400 sft.

4.2 Tilt Angle Calculation

In order to maximize the panel efficiency adjust the tilt angle β must be adjusted in such a way that it will get the maximum radiation. The panel is adjusted by adjusting the tilt angle in each season. Or, the tilt angle can be made equal to the tilt angle needed in winter as, winter is the worst condition.

But, due to the increasing cost and complexity it is decided to use a fixed tilt angle and to get the most energy over the whole year.

Formula used for calculating the tilt angle is,

$\beta = 0.76 * \text{Latitude} + 3.1°$

Dhaka is situated in Latitude = 23.723°

$\beta = 0.76 * 23.723° + 3.1° = 21.13° = 21°$

4.3 Row Distance Calculation

One of the boundary conditions for the installation and performance of PV modules is to determine the correct distance between two consecutive arrays.

To avoid excessive shadowing, the arrays have to be spaced apart by a distance, d , in relation to the module width a

$d/a = \cos\beta + \sin\beta / \tan \xi$

and

$\xi = 90 - \delta - \phi$

Figure 4.1 shows arrangement of a large number of rows of modules.

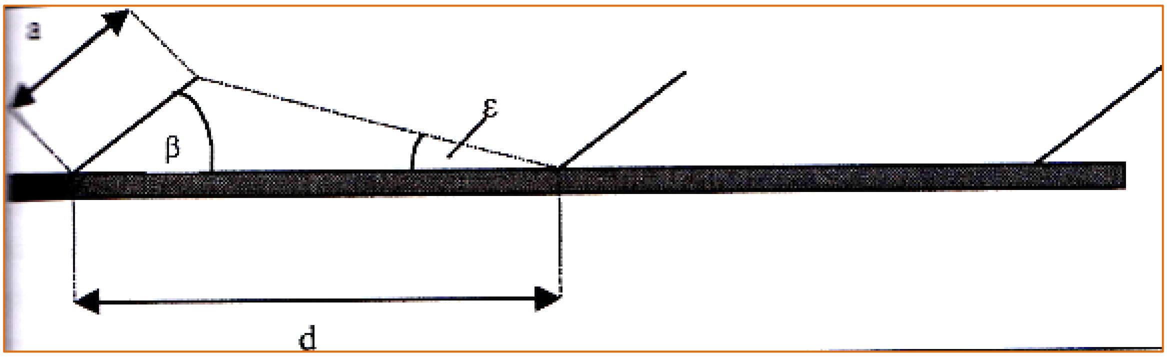


Figure 4.1: Arrangement Of A Large Number Of Rows Of Modules

where

d= distance between two consecutive arrays

a=module width

ϕ = geographic latitude

δ = ecliptic angle = 23.5°

ξ = shadowing angle

β = optimum tilt angle = angle between module and ground

in case of Dhaka , ϕ = 23.723°

β = 21°

now ξ and d/a are calculated below

$$\xi = 90^\circ - 23.723^\circ - 21^\circ = 42.77^\circ$$

$$d/a = \cos 21^\circ + \sin 21^\circ / \tan 42.77^\circ = 1.32$$

4.4 Components Details

Solar PV system includes different components those should be selected according to the system type, site location and application. These are described below.

4.4.1 The PV module details

The first component for solar PV system is solar PV module which converts sunlight into DC electricity. PV Power operates on the principle that electricity will flow between two semiconductors (typically crystalline silicon) when they are put in contact with each other and exposed to light. By linking a number of these 'cells' into a Panel (also called a Module), a useful flow of electricity can be generated.

Only a few days back solar PV modules were imported from China or other countries. Nowadays some companies produce solar PV modules in Bangladesh. They design, manufacture, supply and install renewable energy solutions. “Electro Solar Power Limited' is a leading company in this sector.

The Electra solar band solar PV module adopts high efficient mono-crystalline silicon and is making up of solar cell, EV coating, iron-thinned toughened glass and TPT.

These modules adopt advanced and reliable far infrared automatically welding technique, high vacuum heating lay pressure craftwork, anode oxidation treatment aluminum alloy side frame, water-proof cable box etc, characterized by reasonable structure, anti-ultraviolet, and aging resistances and wind¬proof intensity 2400 Mpa

200 Wp Mono-crystalline solar module has been selected for this system designing. The specifications provided by the company are given in **Appendix A.** In figure 4.2 the mono-crystalline silicon solar panel is shown

4.4.2 Sizing the inverter

Inverters are used to convert the DC output of PV or a storage battery to AC electricity, either to be fed into the grid or to supply a stand-alone system. There are many different types of power electronic topologies used in the market. This solar system is the grid connected one. The on grid solar inverter be used with a connection to grid or power lines.. The advantage of this type is not to worry any power waste because by connecting inverter to the grid, it can save any surplus electricity.

20 kW grid connected solar inverter with high efficiency for plant manufactured by Hubei Tress Technologies Co., Ltd is used for our system. The product details are given in **Appendix A.** In figure 4.3, Grid connected solar inverter is shown.

Figure4.3: Grid connected solar inverter

Figure 4.2 : Mono-crystalline Silicon Solar panel

4.4.3 Sizing the battery

The battery type recommended for using in solar PV system is deep cycle battery. Deep cycle battery is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to operate the appliances at night and cloudy days. To find out the size of battery, calculation are shown below:

1. Calculate total Watt-hours per day used by appliances.
2. Divide the total Watt-hours per day used by 0.85 for battery loss
3. Divide the answer obtained in item 2 by 0.6 for depth of discharge.
4. Divide the answer obtained in item 3 by the nominal battery voltage
5. Multiply the answer obtained in item 4.4 with days of autonomy (the number of days that you need the system to operate when there is no power produced by PV panels) to get required Ampere-hour capacity of deep-cycle battery.

Battery Capacity (Ah) = (Total Watt-hours per day used by appliances × Days of autonomy) / (0.85 x 0.6 x nominal battery voltage)

4.4.4 Charge controller rating

The solar charge controller is typically rated against Amperage and Voltage capacities. Select the solar charge controller to match the voltage of PV array and batteries and then identify which type of solar charge controller is right for your application. Make sure that solar charge controller has enough capacity to handle the current from PV array.

For the series charge controller type, the sizing of controller depends on the total PV input current which is delivered to the controller and also depends on PV panel configuration (series or parallel configuration).

According to standard practice, the sizing of solar charge controller is to take the short circuit current (lsc) of the PV array, and multiply it by 1.3

Solar charge controller rating = Total short circuit current of PV array ×1.3

4.4.5 Connecting accessories and safety components

4.4.5.1 PV Combiner box:

Combiner box is used to connect the solar panels and grid tied solar inverter. The Product details of the combiner box are given in Appendix .Combiner box is shown in figure 4.4.

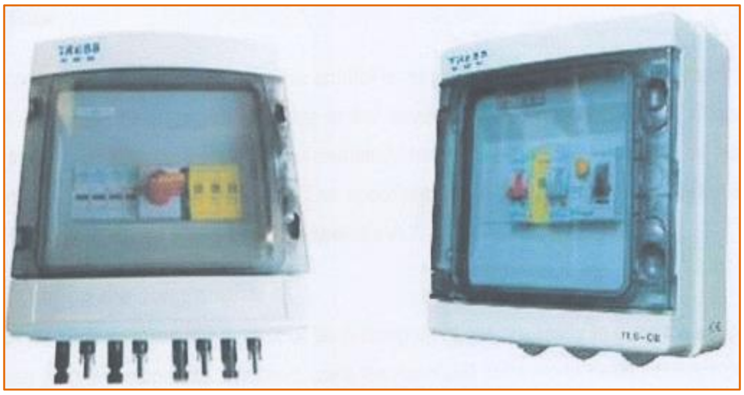


Figure 4.4 : PV Combiner Box

4.4 5.2 Mounting Structures

Solar Panel Bracket of Flat Roof manufactured by the company Haining Chuangyaun Solar Energy Technology Co, Ltd. Used for mounting the modules with the flat root. Technical details are given in Appendix . Mounting Structures is shown in Figure 4.5

Figure 4.5: Mounting Structures

4.4.5.3 Filter

Power converter's output signal harmonic control is currently becoming immensely important in medium and high power applications due to the development of new grid codes. Otherwise, inverters generate harmonics that are subsequently transmitted into the power bus of the grid. So filters are used for system stability stability. The specifications of PV Photovoltaic Inverter Series Filters ROHS compliance is provided in Appendix .

4.5 Integrating the components

The steps of designing the system are described below sequentially:

a) Distance between two consecutive arrays have to be determined :

From previous equation it is know that relation between d and a,

where

d= distance between two consecutive arrays

a=module width

$d/a = \cos 21° + \sin 21° / \tan 42.777° = 1.32$

from the specification produced by the manufacturer of the selected 200 Wp Mono-crystalline solar module,

module width = 1.58m = 5.18ft =5 ft 2 inch

module length = 0.808m=2.65 ft = 2ft 8 inch

$d = 1.32 \times 5.18$ ft= 6.84 ft= 6 ft 10 inch

So the distance between two consecutive arrays, d = 6 ft 10 inch.

And the minimum spacing between two consecutive arrays to avoid shadowing = 1 ft 8 inch = 20 inch

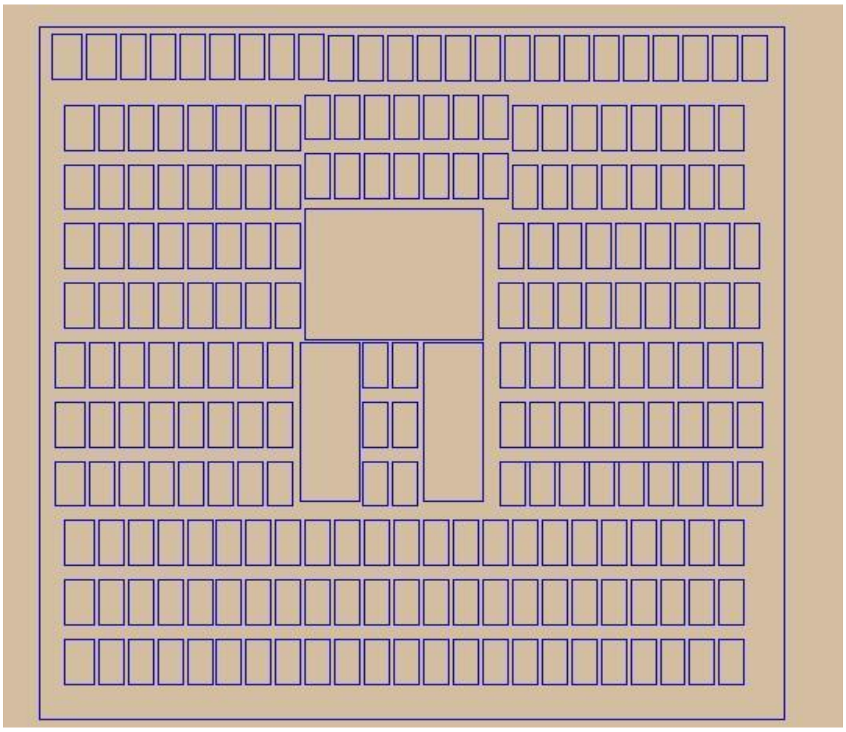


Figure 4.6: System arrangement of solar panels on the roof top by AutoCAD design

b) Arrangement of large number of solar arrays:

The available area for installing the solar system in the flat roof is 5400 sft.

From the manufacturer specification the area required for a single module is 5.18×2.65 sft = 13.727 sft

And minimum spacing to avoid self shadowing = 20 inch

And minimum spacing between two module in a single array = 6 inch

Using AutoCAD software, from the figure 4.6 it is found that the maximum number of modules that can be mounted on the roof is 230

c) Connection of the solar modules

From the manufacturer specification,

Maximum DC input for the 20kw grid tied inverter = 360 volt

PV module output voltage = 34.92 volt

So maximum no of modules to be connected in series = 10

An array consists of 10 modules supplying Dc output voltage =10×34.92 =349.2 volts

d) Connection of the arrays with grid tied inverter

As maximum no of modules to be connected in series is 10, so there are 23 no of arrays to be connected to the inverter.

In order to reduce connection to the inverter PV Combiner box is used. Each combiner box can simultaneously access 6 PV arrays.

As a result 4 no of combiner boxes are required to connect 23 array.

CHAPTER 5

CALCULATION OF TOTAL SOLAR POWER

5.1. Average Incident Solar Radiation

Table 5.1 : The average incident solar radiation of one year at Dhaka **(NASA)**

Month	Average incident solar radiation ($kWh/m^2/day$)	Average incident solar radiation (kW/m^2)
January	4.182	0.174
February	4.677	0.195
March	5.546	0.231
April	5.654	0.236
May	5.578	0.232
June	4.475	0.186
July	3.895	0.162
August	4.117	0.172
September	3.964	0.196
October	4.704	0.165
November	4.250	0.177
December	4.058	0.169
Annual average	4.591	0.191

In figure 5.1 solar radiation map of a single year is shown and in figure 5.2 hourly variation of solar radiation of a single year is shown

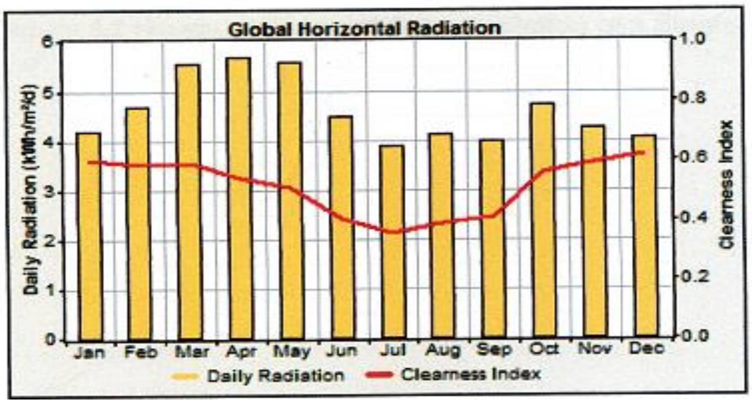


Figure 5.1: Solar Radiation Map of a Single Year

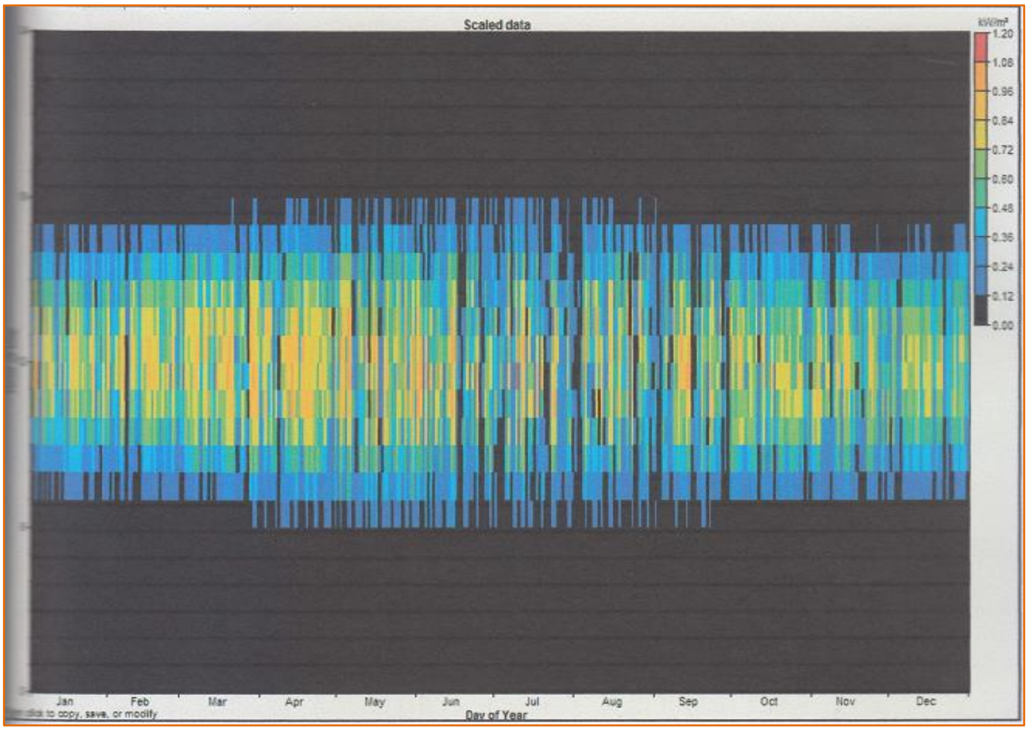


Figure 5.2: Hourly Variation of Solar Radiation of a Single Year

5.2 Calculation of module efficiency

In order to calculate the module efficiency we can use the formula written below

$\eta = (Isc \times Voc \times FF)/P_{IN}$

Where

η = Module Efficiency

Isc = short Circuit current

Voc= Open Circuit Voltage

FF= Fill Factor = Vmp × Imp

Vmp = Optimum operating voltage

Imp = Optimum operating current

P_{IN}= Input Solar Power

For this design purpose 200W Mono-crystalline solar module is used manufactured by **Electro Solar Ltd.** from the technical specifications given it is shown that

at STC(at 25°C and AM1.5),

Isc = short Circuit current =6.5 A

Voc= Open Circuit Voltage =43.2 V

Vmp = Optimum operating voltage =34.4 V

Imp = Optimum operating current = 5.81 A

FF= Fill Factor = (Vmp* Imp)/(Isc * Voc)= (34.4V * 5.81 A)/(6.5 A* 43.2V) = 0.71

Dimensions of the module = 1.58m * 0.808m * 0.035m

Pin= Input Solar Power = 1000W/m^2= 1000* 1.58 * 0.808 W

= 1276.64 W =1277 W

η = ((6.5*43.2*0.71)/1277)*100 = 15.61 %

5.3 Average Output Power Calculation

The monthly average output power from the solar module and the total system output can be calculated from the following equation.

$Ppv = Ypv * f_{PV} * (G_T/G_{T,STC})$

Where

Ypv= the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

fpv= the PV derating factor [%]

G_T= the Solar radiation incident on the PV array in the current time step [kW/m^2]

$G_{T,STC}$= the incident radiation at standard test conditions = 1 kW/m^2

As the temperature coefficient of power is very small. PV output power is calculated neglecting the effect of temperature.

From the technical specifications of the used **200W Monocrystalline solar module** it is know that,

At STC (at 25°C and AM1.5),

Rated capacity of the PV module =200 W.

In Chapter 4 it is found that the maximum number of modules that can be mounted on the roof is 230

So Peak output Power of the designed system =200× 230 W= 46kW

Ypv = the rated capacity of the PV array =46 kW

f_{PV} = 0.8

$G_{T,STC}$ = the incident radiation at standard test conditions = 1 kW/m^2

For the month of January,

G_T= the solar radiation incident on the PV array in January = 0.174 kW/m^2

Ppv = 46 × 0.8 × (0.174/1) kW = 6.40

Table 5.2 : The Monthly average output power for monocrystalline solar module

Month	Average incident solar radiation (kWh/m2/day)	Output power from the designed system (kw)
January	0.174	6.40
February	0.195	7.18
March	0.231	8.50
April	0.236	8.68
May	0.232	8.53
June	0.186	6.84
July	0.162	5.96
August	0.172	6.33
September	0.196	7.21
October	0.165	6.07
November	0.177	6.51
December	0.169	6.22
Average Output Power	0.191	7.03

Average hours of operation in a day = 12 hrs.

So, total hours of operation in a year = 4380 hrs/yr.

Average solar energy production /yr = 7.03 kW * 4380 hr/yr

= 30791.4 kWh/yr= 30792 kWh/yr.

5.4 Output Power of Different Types of Modules

5.4.1 Polycrystalline solar modules

The change in system output power can be calculated if 200w polycrystalline solar cell is used instead of mono-crystalline solar module.

Efficiency:

From The specification given by the manufacturer the output power is calculated.

At STC(at 25°C and AM1.5),

I_{sc} = short Circuit current =8.1 A

V_{oc} = Open Circuit Voltage =33.6 V

V_{mp} = Optimum operating voltage =26.2 V

I_{mp} = Optimum operating current = 7.63 A

FF= Fill Factor = $(V_{mp} \times I_{mp}) / (I_{sc} \times V_{oc}) = (26.2\ V \times 7.63\ A) / (8.1\ A \times 33.6\ V) = 0.73$

Dimensions of the module = 1.482m × 0.992m × 0.035m

P_{IN}= Input Solar Power =1000 W/m^2 = 1000 × 1.482 ×0.992w == 1470 W

$$\eta = (8.1 \times 33.6 \times 0.73 \times 100)/1470 = 13.5\%$$

Calculation of output power:

No of polycrystalline modules that can be installed in the roof top is 205.

Peak output power of the designed system =205 ×200 W =41 kW.

So the average output power can be calculated as follows,

For the month of January,

G_T= the solar radiation incident on the PV array in January = 0.174 kW/m^2

$$Ppv = 41\times 0.8 \times (0.174/1) \text{ kW}$$
$$= 5.71\text{kW}$$

Table 5.3 : The Monthly average output power for monocrystalline solar module

Month	Average incident solar radiation (kWh/m2/day)	Output power from the designed system (kw)
January	0.174	5.71
February	0.195	6.4
March	0.231	7.58
April	0.236	7.74
May	0.232	7.61
June	0.186	6.10
July	0.162	5.31
August	0.172	5.64
September	0.196	6.4288
October	0.165	5.412
November	0.177	5.80
December	0.169	5.54
Average Output Power	0.191	6.26

Average solar energy production /yr. = 6.26 kW × 4380 hr/yr

= 27418.8 kWh/yr = 27,419 kWh/yr.

5.4.2 Thin Film solar modules

The change in system output power if 200W Thin Film solar cell (Model No. SLP-024) is used instead of monocrystalline solar module.

Efficiency:

From The specification given by the manufacturer the output power is calculated

At STC(at 25°C and AM1.5),

I_{sc} = short Circuit current =8.22 A

V_{oc}= Open Circuit Voltage =36.3 V

V_{mp} = Optimum operating voltage =29.1 V

I_{mp} = Optimum operating current = 7.40 A

FF= Fill Factor = (Vmp × Imp)/ (Isc × Voc) = 0.722

Dimensions of the module = 1.956m × 0.992m × 0.05m

P_{IN}= Input Solar Power = 1000W/m^2= 1000× 1.58 × 0.808W = 1940W

η =(8.22×36.3×0.722×100)/1940

= 11.1%

Calculation of output power:

No of thin film modules that can be installed in the roof top is 194. Maximum output power of a single module is180W

Peak output power of the designed system =180*194W =34.92 kW

So the average output power can be calculated as follows,

For the month of January,

G_T= the solar radiation incident on the PV array in January = 0.174 kW/m^2

Ppv = 34.92 × 0.8 × (0.174/1) kW

=4.86 kW

Table 5.4: The monthly average output power for thin film solar module

Month	Average incident solar radiation (kWh/m2/day)	Output power from the designed system (kw)
January	0.174	4.86
February	0.195	5.45
March	0.231	6.45
April	0.236	6.59
May	0.232	6.48
June	0.186	5.196
July	0.162	4.525
August	0.172	4.80
September	0.196	5.475
October	0.165	4.609
November	0.177	4.944
December	0.169	4.72
Average Output Power	0.191	5.335

Average solar energy production /yr =5.335 kW × 4380 =23367.3 kWh/yr

Table 5.5: Calculated Efficiencies and Average Output Power for Different Types of Solar Panels:

Type of the Module	Efficiency (%)	Average Output (kw)
Mono-crystalline Solar Panel	15.6	7.03
Poly-crystalline Solar Panel	13.5	6.26
Thin Film Solar Panel	11.1	5.335

CHAPTER 6

COST ANALYSIS OF THE SYSTEM AND COMPARISON OF VARIOUS SOLAR CELLS

6.1 Capital Cost

Capital costs are costs incurred on the purchase of land, buildings, construction and equipment to be used in the production of goods or the rendering of services, in other words, the total cost needed to bring a project to a commercially operable status. However, capital costs are not limited to the initial construction of a factory or other business. For example, the purchase of a new machine that will increase production is a capital cost [18].

In a grid-connected solar PV system, the capital cost includes mainly the cost of the solar panels, Grid-connected Solar Inverter, PV Combiner Box and Solar Panel Bracket. Approximate cost of PV power system design has been calculated by evaluating the value of these components. The effect of temperature variation has been excluded in the cost calculation. However, the cost will vary if temperature control is included in the system design.

Table 6.1 : Capital Cost Calculation for Grid –connected Solar PV Array System [19]

Item Number	Name of the Item	Quantity	Price per Unit	Price in USD
1.	Solar PV Array	230 Modules	$ 1.5 / Watt	$ 69000
2.	Grid connected Solar Inverter	1 Set	$ 3730	$ 3730
3.	PV Combiner Box	25 Set	$ 200	$ 5000

4.	Solar Panel Bracket	25 Set	$ 200	$ 5000
				Total Cost = $ 82730

Taking 1$=78.00 Taka,

Total capital cost (in BDT) = 82730×78 = 64, 52,940 Taka = 64, 53,000 Taka

6.2 Replacement Cost

Replacement cost is the amount it would cost to replace an asset at current prices. If the cost of replacing an asset in its current physical condition is lower than the cost of replacing the asset so as to obtain the level of services enjoyed when the asset was bought, then the asset is in poor condition and the firm would probably not want to replace it [20]. The replacement cost of solar panels and accessories are almost negligible unless they are purchased from a company that's not very reputable [21]. For example, most inverters come with a life-expectancy of approximately 10 years. As a result, most inverters need replacement after about 11 years of service. Replacing an inverter is usually the most expensive aspect of a solar system, with replacement costs ranging between $3,000 and $20,000 each time. However, a long term solar energy can be purchased to cover this cost [22]. In this calculation, this has been neglected.

6.3 Operation and Maintenance Cost

An operating expense, operating expenditure, operational expense, operational expenditure is an ongoing cost for running a product, business, or system [23]. The operation and maintenance cost of solar system is quite low. It should average 1% to 3% of capital cost per year over the first 20 years [24]. This is the thumb rule for calculating the operation and maintenance cost of the solar PV system. For this system it is taken 3% of the capital cost as the operation and maintenance cost.

So the Operation and Maintenance Cost cost of our system is =64, 53,000 × 0.03 = 1, 93,590 taka/yr.

6.4 Lifetime

Photovoltaic panels are a key element in a solar system. They have an effective life span of about 20 to 25 years. Their value and wattage output decreases steadily over time [25]. Whereas the second most important component, the inverter, has a life-expectancy of approximately 10 years. Ordinarily, these systems have a fairly long lifespan, lasting more than 20 years. Most manufacturers offer 10-20 year warranties. The lifespan varies based upon the amount of usage. Proper routine maintenance will help to prolong the lifespan as well.

6.5 Total Cost Calculation

Since the replacement cost is neglected here , the total cost includes only capital cost and operation and maintenance cost.

The total capital cost = 64, 53,000 Taka

The annual operation and maintenance cost = 1, 93,590 Taka.

6.6 Total Revenue Calculation

The proposed system is a grid-tied system without any emergency load. All the power produced by the panels is fed into the grid. So any charge storage system e.g. battery and charge controller is not needed. Since this concept is quite new in our country, we have followed the sell-back price policy of foreign countries in our analyses. For example in Queensland, Australia, it is two times higher than the electricity price charged by the electricity supplying companies [26], [27]. The latest retail tariff in Bangladesh for residential consumers (consuming between 300- 400 units) = 4.93 Taka per unit (i.e. per KWh) [28]. So sell-back price is taken as = 2x4.93 Taka= 9.86 Taka. In all further calculations, it is used .

Average energy produced from the solar system per year is= 30792kWh/year

So, the revenue earned by selling total electricity

= 2×4.93× (Average energy produced from the solar system per year)

= 2x4.93x30792 Taka

= 3, 03,609.12 Taka/yr

6.7 Comparison Between Different Types of Modules

The cost of the system and revenue earned by the system by using three types of solar cells will be compared. In actual design, mono-crystalline solar panel have been used. But now it will now be found out what would be the cost of the system and the revenue if poly-crystalline or thin-film solar panels had been used. The replacement cost and operation and maintenance cost has been neglected in this calculation. The findings are given in the following articles.

6.7.1 Cost comparison

Table 6.2 : Capital Cost Calculation for Grid –connected Solar PV Array System using poly-crystalline solar panels

Brand name: FEIYA

Model Number: FY-54-200P

Item Number	Name of the Item	Quantity	Price per Unit	Price in USD
1.	Solar PV Array	200 Modules	$ 1.079 / Watt	$ 43160
2.	Grid –connected Solar Inverter	1 Set	$ 3730	$ 3730

3.	PV Combiner Box	25 Set	$ 200	$ 5000
4.	Solar Panel Bracket	25 Set	$ 200	$ 5000
				Total Cost = $ 56890 BDT 4437420

The Operation and Maintenance Cost of the system is = Capital cost ×0.03

. =44,37,420×0.03

=1,33,123 Taka/yr

Table 6.3 : Capital Cost Calculation for Grid –connected Solar PV Array System using thin film solar panels :

Brand name : Powerman[40]

Model Number : HT-152P

Item Number	Name of the Item	Quantity	Price per Unit	Price in USD
1.	Solar PV Array	200 Modules	$ 1.162 / Watt	$ 46480
2.	Grid –connected Solar Inverter	1 Set	$ 3730	$ 3730
3.	PV Combiner Box	25 Set	$ 200	$ 5000
4.	Solar Panel Bracket	206 Set	$ 200	$ 5000

				Total Cost = $ 60210 BDT 4696380

The Operation and Maintenance Cost of the system is,

= Capital cost×0.03

=4696380× 0.03

. =1, 40,891Taka/yr

Table 6.4: Cost Comparison between three types of solar panels

Type of the Module	Efficiency (%)	Average Output (kw)
Mono-crystalline Solar Panel	$ 1.5 / Watt	64,53,000
Poly-crystalline Solar Panel	$ 1.079 / Watt	4437420
Thin Film Solar Panel	$ 1.162 / Watt	4696380

The comparison indicates that mono-crystalline solar panel has the highest price, thin film solar panel has medium price and poly-crystalline solar panel has the lowest price. So polycrystalline solar panel is most feasible for the system.

6.7.2 Revenue comparison

1. Total revenue earned if poly-crystalline solar panels are used:

Average energy produced from the solar system per year is=27418 .8 kWh

So, the revenue earned by selling total electricity = 2x4.04x (Average energy produced from the solar system per year) =2×4.93Taka×27418.8 KWh =2,70,349.36 Taka/yr

2. Total revenue earned if thin-film solar panels are used:

Average energy produced from the solar system per year is= 23367.3 kWh/yr

So, the revenue earned by selling total electricity = 2x4.04x (Average energy produced from the solar system per year)= 2 ×4.93 Taka × 23367.3= 230401.578 taka/yr

CHAPTER 7

EFFECT OF TEMPERATURE ON SOLAR CELL

7.1 Temperature Dependence of Solar Cell

Temperature affects how much energy a solar panel can produce. When a solar cell is heated, it becomes less efficient. The amount of energy a solar panel can produce depends on its efficiency. The efficiency is determined by comparing how much power the solar cell produces to the amount of light that shines on it. This is measured by illuminating the solar cell with a calibrated light and measuring the current produced at different voltages.

This measurement gives us current as a function of voltage which is plotted on a graph. For a solar cell, this function looks like the one shown in red in figure. Voltage vs. current relationship of a solar cell is shown in figure 7.1

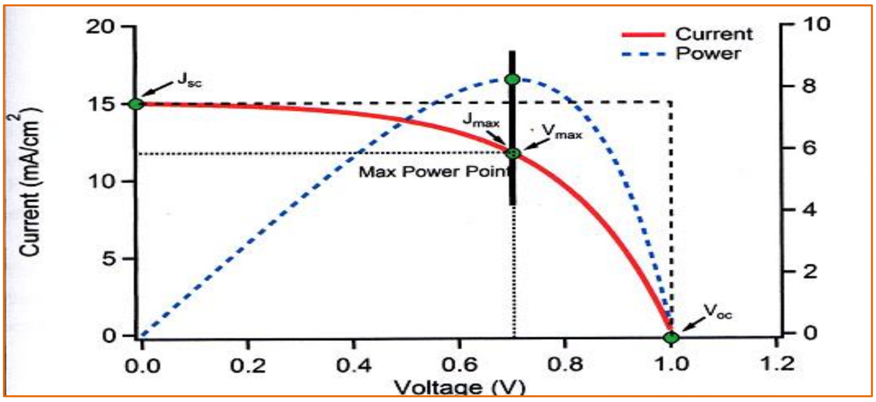


Figure 7.1 Voltage vs. Current Relationship of a Solar Cell

The power produced by a solar cell is calculated from the current and voltage with the following equation.

$$P = JV$$

Where

P is the power produced

J is the current and

V is the voltage.

The power is plotted in blue in the figure. Somewhere along the current-voltage curve the power, P, will have a maximum value. This point is called the maximum power point and it is where we calculate the efficiency. The efficiency is given by

$\eta = (J_{max} \times V_{max})/P_{in}$

where

η is the efficiency

J_{max} is the current at the maximum power point

V_{max} is the voltage at the maximum power point and

P_{in} is the power incident on the solar cell (the power from the light shining on it).

This can also be written as

$\eta = (I_{sc} * V_{oc} * FF)/P_{in}$

where

I_{sc} is the current at short circuit (when V = 0)

V_{oc} is the voltage at open circuit (when J = 0) and

FF is the fill factor which describes how "square" the current-voltage curve is. It is the ratio between the two rectangles drawn in the figure.

When the solar cell is heated, the current, J_{sc} will increase, but the voltage, V_{oc}, will decrease. Since the voltage decreases faster than the current increases, the result is that the overall efficiency goes down.

$\eta \downarrow = (I_{sc}\uparrow * V_{oc} \downarrow\downarrow * FF)/ P_{in}$

Although the performance of solar panels does depend on temperature, the effect is not very strong so solar panels can still function properly even in the summer when it is hot outside.

7.2 Output Power vs. Temperature

The following equation shows the relation between output power of solar PV array and temperature.

$$Ppv = Ypv \times fpv \times (G_T/G_{T,STC}) \times [1+\alpha_P \times (Tc-Tc,stc)]$$

Where

Ypv= the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

f_{PV}= the PV derating factor [%]

G_T = the solar radiation incident on the PV array in the current time step [kW/m^2]

G_{STC}= the incident radiation at standard test conditions [1 kW/ m^2]

α_P = the temperature coefficient of power [%/°C]

Tc= the PV cell temperature in the current time step [°C]

T c,stc = the PV cell temperature under standard test conditions [25 °C]

The temperature coefficient of power indicates how strongly the PV array power output depends on the cell temperature, meaning the surface temperature of the PV array. It is a negative number because power output decreases with increasing cell temperature.

Manufacturers of PV modules usually provide this coefficient in their product brochures, often labeled either as "temperature coefficient of power", "power temperature coefficient", or "max. power temperature coefficient".

In November 2007 an experiment was performed that was a non-exhaustive, non-scientific survey of the product brochures available for some of the commonly available

PV modules. The following table contains the average values of the temperature coefficient of power for various types of PV modules in our survey.

Table 7.1: Values of the temperature coefficient of power [% /°C] for different types of PV modules [29]

PV Module Type	Modules in Survey	Modules Reporting	Average Value of ap [%0C]
Polycrstalline silicon	10	7	-0.48
Monocrystalline silicon	8	4	-0.46
Monocrystalline/amorhpous silicon	1	1	-0.30
Thin film amorphous silicon	4	4	-0.20
Thin film CIS	1	1	-0.60

If the product brochure does not specify the value of the temperature coefficient of power, it may contain a graph showing the normalized performance versus cell temperature, like the sample shown below. In such a graph, the slope of the power line (labeled Pmax in this sample) is the temperature coefficient of power. Relationship of normalized power, voc and isc with respect to the cell temperature is shown in figure 7.2

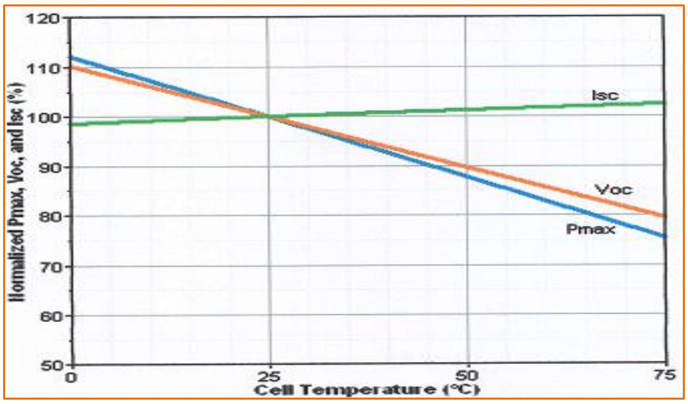


Figure 7.2: Relationship of Normalized Power, Voc and Isc with respect to the Cell Temperature [29].

Some product brochures do not specify the temperature coefficient of power, but do specify the temperature coefficient of the open-circuit voltage. In that case, we can calculate the temperature coefficient of power using the approximation suggested by Duffle and Beckman(1991)

$\alpha_p = \mu Voc/Vmp$

Where

μVoc = the temperature coefficient of the open-circuit voltage [V/°C]

Vmp = the voltage at the maximum power point under standard test conditions [V]

If the brochure does not specify the temperature coefficient of the open-circuit voltage but it contains a graph showing the I-V curve at different cell temperatures, such as the sample shown below, the graph can be used to calculate the temperature coefficient of the open-circuit voltage. Voltage vs. current characteristics curve for different temperatures is shown 7.3 .

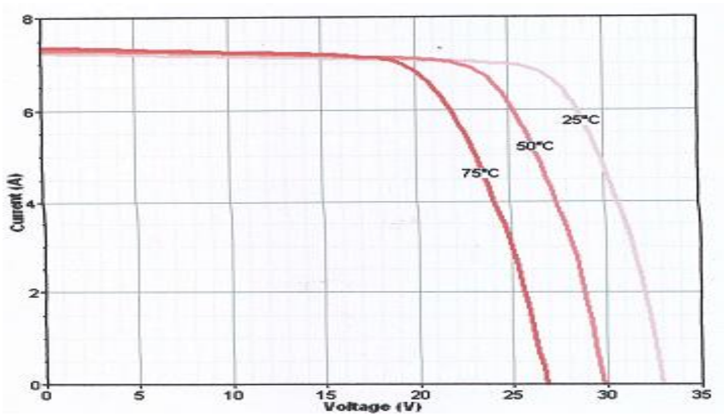


Figure 7.3 Voltage vs. Current Characteristics Curve for Different Temperatures [29]

To do so, the open-circuit voltage (the voltage at the bottom of the IV curve) versus cell temperature have to plotted, and find the slope of that line, as shown in figure 7.4. The slope of that line is the temperature coefficient of the open-circuit voltage. In this example, the slope of the line is -0.124 v/^{0}c

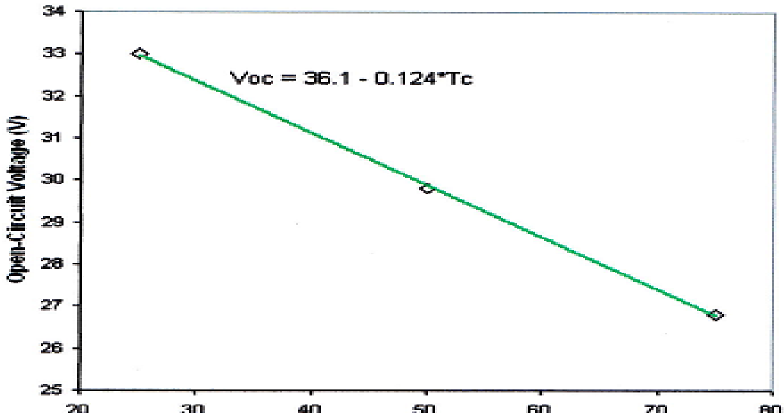


Figure 7.4 :Open-Circuit Voltage (Voc) vs. Cell Temperature Curve.

From the above discussion we can see that there is an inverse relation between output power of the solar module and temperature.

7.3 Output Power Variation With Temperature

Mono crystalline solar panel with 200Wp from Electro Solar Company was selected for our design. The average output power can be calculated at the annual average temperature (27 °C) in this design.

$P_{pv} = Y_{pv} \times f_{pv} \times (G_T/G_{T,STC}) \times [1 + \alpha_p \times (Tc - Tc,stc)]$

where

Ypv= the rated capacity of the PV array, meaning its power output under standard test conditions [kW] =200 Wp

fpv= the PV derating factor [%]=0.8

G_T = the solar radiation incident on the PV array in the current time step [kW/m^2]=4.591 kWh/m^2/day= 0.191 kw/m^2

$G_{T,STC}$ = the incident radiation at standard test conditions [1 kW/m^2]

α_p = the temperature coefficient of power [%/°C] = -0.5 %/°C [From the technical specification sheet provided by the manufacturers] = -0.005/°C

T_C= the PV cell temperature in the current time step [°C]=27 °C

Tc ,stc = the PV cell temperature under standard test conditions=25 °C

The average output power of a single module at 27 °C is P_{AVG}=200x0.8x0.191x(1+ (-0.005) x(27-25)) = 30.2544 W

The total average output drawn from the system= 230x30.2544 W= 6958.512 W= 6.9585 kW

Effect of temperature change:

1. **Increasing the temperature**

   In Bangladesh, the temperature becomes very high during summer. It reaches about 35-40 C at midday. High temperature has an adverse effect on the system output. For example, if the temperature increases above 10° C than the average temperature (27° C), the average output power of a single module becomes= 200x0.8x0.191x(1+ (-0.005) x(40-25)) = 28.268 W. The power is reduced by (30.2544-28.2680) W = 1.9864W.

The total power reduced due to high temperature = No. of panels x Reduced Power

= 230x1.9864 W

= 456.872W

= 457W

2. **Decreasing the temperature**

In the winter, the temperature falls down far below the STC temperature. The temperature becomes 15° C. This situation is convenient for the improvement of the panel output efficiency. At 15° C, the average output power of a single module becomes = 200x0.8x0.191x(1+ (-0.005) x(15-25)) = 32.088 W. The power is increased by

(32.088-30.2544) W = 1.8336 W.

The total power increased due to high temperature = No. of panels × increased Power = 230x 1.8336 W=421.728 W=422 W

The above result indicates that if we can maintain the module temperature approximately around STC temperature during the hot summer days, the efficiency will be improved significantly and we would be able to draw more power from the system.

7.4 Heat Absorbing Methodology

PV solar cell directly converts solar radiation into electricity with efficiency of 9-12%. If the surface temperature can be reduced by 10°C, the cell efficiency will increase by 2.3%. In this design, Forced Water Flow Cooling System was selected to cool down the solar panels during midday. The method is inspired by an experiment held in Indonesia [30].The method is described below.

7.4.1 How the cooling system work

The cold water is supplied from the building's overhead water tank through a pipe towards the solar panels. There are copper pipes attached at the backside of the solar panel in spiral form. Water circulates through these pipes and heat is conducted from the hot solar panels through the copper pipes into the water. The temperature of the water is increased. Forced flowing water causes the replacement of hot water with the cooler one. Forced flow generated by the placing the water tank above the solar cell unit, so the water will flow due to gravity. In figure 7.5 a schematic of the water cooling system is shown and experimental set-up for the water cooling system is shown in figure 7.6.

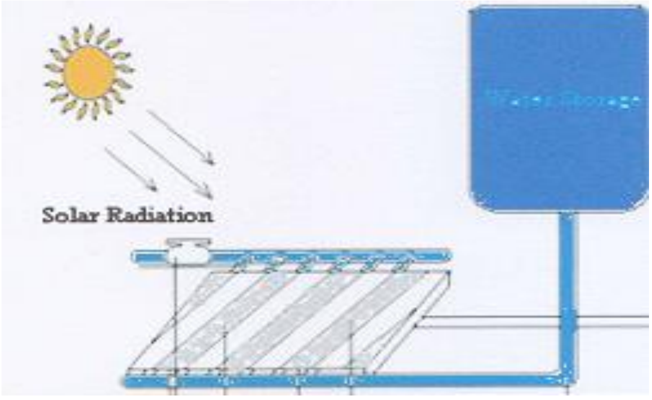


Figure 7.5: A Schematic of the water cooling system

Figure 7.6: The Experimental set-up for the water cooling system

The hot water is then drained into another pipe. The hot water pump is connected to another tank placed at the ground floor. The hot water is collected at this tank. It is further processed for recycle and re-use.

7.4.2 Relationship of temperature of hot water, surface temperature of the panel, output power of panel and cell efficiency with respect to the water flow rate :

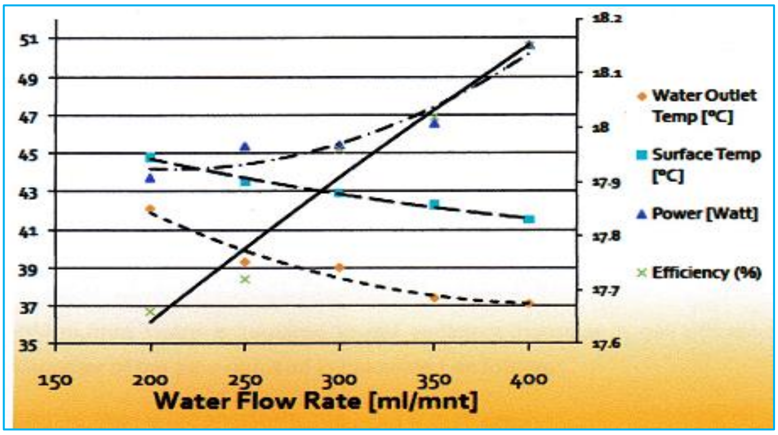


Figure 7.7: Relationship between System Parameters and Water Flow Rate[30].

The above figure 7.7 shows the relationship between different parameters and the water flow rate in mL/minute. The graph shows that if the water flow rate is increased, the cell efficiency increases and surface temperature of the panel decreases almost in a linear pattern.

The flow rates chosen for the experiment were 200, 250, 300, 350 and 400 mL/min. The surface temperature of not cooled solar cells is 52.4°C, higher than that of cooled cell, because the only way of the release of heat from the cells is by free convection and radiation to the environment. The heat release by this method is less compared with the one to the cooling water. The study shows the cooling water flow rate of 400mL/min can reduce the solar cell surface temperature by10.9°C [30].These results was used to design the cooling system in our system.

In this design , water will be supplied at a flow rate of 400 mL/min for 3 hours everyday during the summer which will reduce the panel temperature by 10.9°C. As a result, the cell efficiency will increase by 2.3%.

7.4.3 Required amount of water to reduce the panel temperature by 10.9°C:

Water flow rate to cool down a single panel= 400 mL/min

Water flow rate to cool down 230 panels= 400 × 230 mL/min =92000 mL/min =92 L/min

Total Water flown in 3 hours= (92 L/min × 3 ×60 min) per day

= 16200 L per day

= 16200 X10^{-3} m^3 per day [since 1L= 10^{-3} m^3]

= 16.2m^3 per day

7.4.4 Cooling system arrangement

First step : the diameter of the pipe in a single module have to be calculated

400mL/min water is required to get sufficient increase in cell efficiency. Now the diameter of the pipe required is calculated as follows:

400 mL/min = (400/1000)/3.786 gpm = 0.11 gpm

In figure 7.8 cooling water flow path within a solar module is shown .

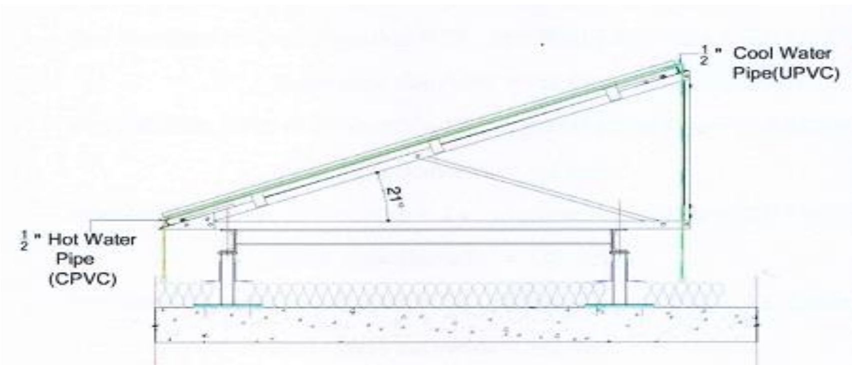


Figure 7.8: Cooling Water Flow Path within a Solar Module

If UPVC pipe is selected for the system, the lowest diameter pipe for supplying water in market is 1/2 inch, which allows water flow up to 10 gpm. To control the 400mL/min water flow through the 1/ 2 inch pipe we have use control valve.

Second step: the diameter of other pipes used to supply cool water has to be calculated

To reduce the total no of pipes 230 no of solar modules have been grouped into 8 sections (Section 1 to Section8).

The required diameter for input pipe in a section is calculated as followes :

For Section 1:

No of modules in this group are 72. Flow of water required for each module is 400mL/min for sufficient cooling. So water flow through the input pipe in this section be 72 *400mL/min = 28.8 L/min.

28.8 L/min = 28.8/3.786 gpm = 7.61 gpm.

So,1/2 inch diameter pipe will be sufficient.

Similarly input pipe capacities of other sections are found to be

For Section 2:

No of modules = 24 , required water flow = 9.6 L/min.

Input pipe diameter = 1/2 inch

For Section 3:

No of modules = 18 , required water flow = 7.2 L/min. Input pipe diameter = 1/2 inch

For Section 4:

No of modules = 24 , required water flow = 9.6 L/min. Input pipe diameter = 1/2 inch

For Section 5:

No of modules = 24 , required water flow = 9.6 L/min. Input pipe diameter = 1/2 inch

For Section 6:

No of modules = 22 , required water flow = 8.8 L/min. Input pipe diameter = 1/2 inch

For Section 7:

No of modules = 24 , required water flow = 9.6 L/min. Input pipe diameter = 1/2 inch

For Section 8:

No of modules = 22 , required water flow = 8.8 L/min. Input pipe diameter = 1/2 inch

Finally flow of water in main pipe which supply water from overhead water tank is found to be 230*0.4 L/min =92 L/min and its diameter will be 3/4 inch

.

Third step : is to calculate the diameter of hot water collecting pipe

Hot water from solar modules should be collected using CPVC pipe, the capacity of which is similar to the UPVC pipe.

So 1/2 inch and 3/4 inch CPVC pipes will be used for designing hot waterflow.

CHAPTER 8

BIOGAS: CALCULATION OF ELECTRICITY GENERATION FROM WASTE

8.1 Calculation of Electricity Generation From Poultry Waste

Let the number of broiler = n

From practical data each broiler gives 100 gm of waste per day [31].

So, from n number of broilers the total available waste,

$$= (n \times 100)/1000$$

$$= 0.1n \text{ kg}$$

Again, practically 0.07 m^3 of biogas is got from I kg of waste [32].

So, total biogas obtained from n number of broilers

$=0.1n \times 0.07 \text{ m3}=0.007n \text{ m3}$

From each cubic meter biogas the produced electricity is 1.4 kWh [32].

So, from n number of broilers the electricity obtained

$= 0.007n \times 1.4 =.0098n \approx 0.01n$ kWh

lf the electricity is used for I0 hours/day then capacity of the poultry farm for electricity generation can be obtained by the following equation

Capacity= 0.01n/10 kW, where n is the number of broiler

As example ,if a farm has 10,000 number of broiler then it's capacity

$$C=(0.01 \times 10,000)/10 = 10 \text{ kW}$$

For only one broiler the produced electricity per day,

= 0.01/10 = 0.001 kW =1 W

So, finally it can be said that 1w electricity is produced from one broiler and 1 kW electricity is produced from 1 thousand broilers for 10 hours/day electricity consumption.

Table 8.1: Amount of Biogas and Electricity production from poultry waste.

No of broiler	Estimated gas production capacity(m^3)	Waste required/day (kg)	Water required per day (liter)	Required manure for primary charging(kg)	Estimated using time (hour)	Capacity of electricity generation (kW)
1000	7	90	180	4500	5	2
10,000	70	920	1840	40,000	10	10
30,000	210	2900	5800	120,000	10	30
50,000	350	4400	8800	220,000	10	50
1,00,000	700	8800	17600	440,000	10	100

8.2 Calculation of Electricity Generation From Cow Dung

On an average each cow gives 10 kg cow dung per day [31].

For n number of cows, total cow dung= 10n kg

Again, practically a 0.037m3 biogas is produced from I kg of waste [32], [33].

So, total biogas obtained from n number of cows

$= 10n \times 0.037\ m^3 = 0.37n\ m^3$

From each cubic biogas the produce electricity is 1.4 kWh [32]

So, from n number of cows electricity obtained = $0.37\ n \times 1.4 = 0.518\ n$ kWh.

For 10 hours/day, the capacity of the electricity generation can be obtained by the following equation.

Capacity = 0518n/10 kw , where n is the number of broiler

As for example, if a farm has 20 number of cow then its capacity

C = 0.518 × 20/10

=1 kW

For only one we get electricity per day,

= 0.518/10 =0.0518 kw =50 W

So, finally it can be said that lW electricity is produced from one broiler and 1 kW electricity is produced from I thousand broilers for l0 hours/day electricity consumption.

Table 8.2: Amount of Biogas and Electricity production from cow dung.

No of cow	Estimated gas production capacity(m^3)	Waste required/day (kg)	Water required per day (liter)	Required manure for primary charging for HRT of 40 days (kg)	Estimated using time (hour)	Capacity of electricity generation (kW)
20	7.4	200	200	8000	5	2.0
50	18.5	500	500	20,000	10	2.5
100	37	1000	1000	40,000	10	5
250	92.5	2500	2500	1,00000	10	12.5
500	185	5000	5000	2,00000	10	25

8.3 Calculation of Electricity Generation From Human Waste

On an average each person gives 0.5 kg of waste per day [31].

For n numbers of persons the total waste= 0.5n kg

At ordinary temperature (30^0 C) biogas obtained from human waste 0.365 m^3/ kg TS [34]

Again TS value of human waste =20%

So, total biogas obtained from n number of persons

$= 0.5n \times 0.2 \times 0.365$ m3 $= 0.0365n\ m^3$

From each cubic meter biogas the produced electricity is 1.4 kWh [32]

So, from n number of persons electricity obtained

$= 0.0365n \times 1.4 = 0.0511n$ kWh

If the electricity is used for 2 hours/day then capacity of the farm for electricity generation can be obtained by the following equation

capacity= 0.0511n kW/2 , where n is the number of person

As example, if a 5 storied building has 45 number of persons then its capacity

$$C = (0.0511 \times 45)/2$$

$$= 1.15 \text{ kW}$$

CHAPTER 9

DESIGN OF BIOGAS PLANT FOR A SINGLE HOUSE

9.1 Design Parameters [33], [34]

9.1.1 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 about40-45 days [33].

So, for Bangladesh HRT=40 days. The HRT for poultry manure is shown in figure 9.1.

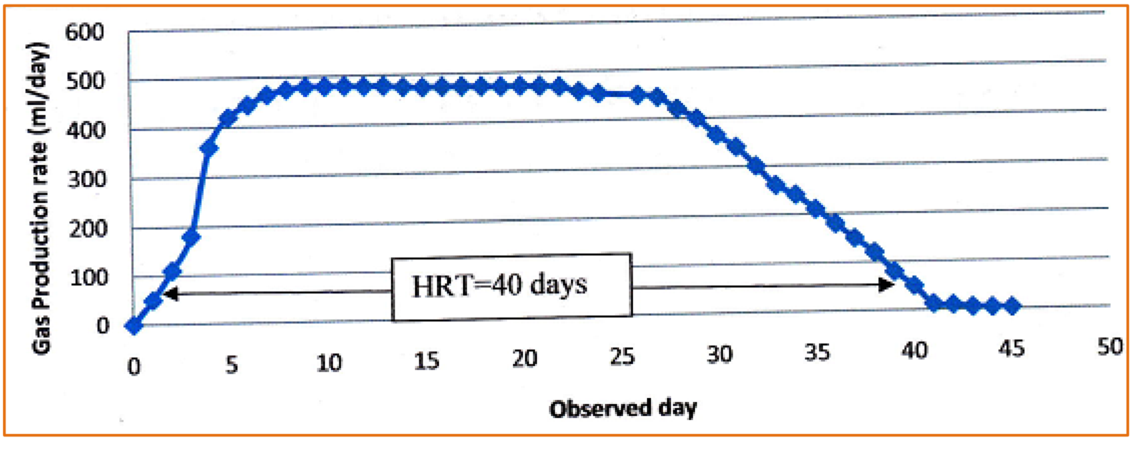


Figure 9.1: Hydraulic retention time (HRT) for poultry manure.

9.1.2 Total Solid (TS)

Total solid indicate the amount of material without considering the liquid part. Total solid contained in a certain amount of materials is usually used as the material unit to indicate the biogas producing rate of materials.

Most favorable TS value desired is 8% for smooth fermentation process.

9.1.3 Fresh Discharge

Fresh discharge is the total amount of manure including moisture content directly obtained from the cow, chicken, human etc.

9.1.4 Liquid Part

It is the amount of water to be added with fresh discharge to make the TS value 8%. The table 9.1 shows the amount of solid and liquid contents in different types of waste.

Table 9.1: The solid and liquid content of common fermentation materials. [34]

Materials	Dry Matter content (%)	Water content (%)
Human	20	80
Cow	16	84
Chicken	20	80
Pig	20	80

9.1.5 Relationship Between Temperature And HRT (For Constant TS Value Of 8%)

When the temperature increases, then the HRT value decreases. This is depicted in figure 9.2. On the other hand, table 9.2 shows the amount of TS value and water to be added for different types of waste.

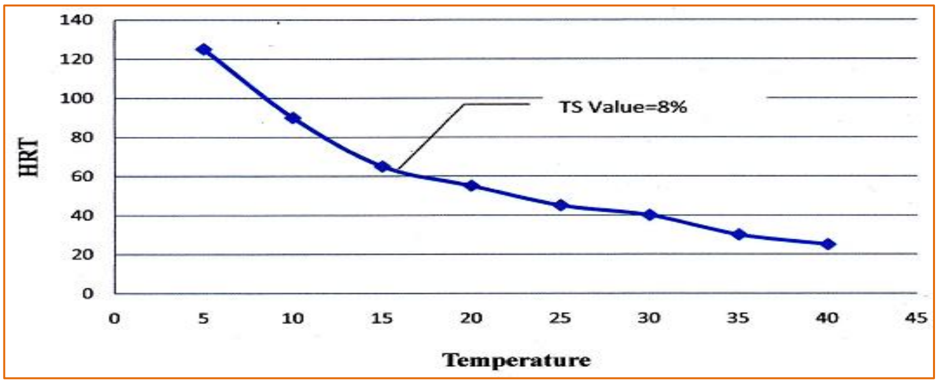


Figure 9.2: Temperature Vs. HRT curve at constant TS value. [34]

Table 9.2:Table showing discharge per day, TS value of fresh discharge ahd water to be added to make favorable TS condition. [34]

Kinds	Body weight (Kg)	Discharge per day (kg)	TS value of fresh discharge (% by wt)	Water to be added with fresh discharge to make the TS value 8% (kg)
Human	50	0.5	20	0.75
Cow	200	10	16	10
Chicken	1.5	0.1	20	0.15
Pig	50	5	20	7.5

9.1.6 C/N Ratio

It is the carbon to nitrogen ratio. This ratio indicates the biogas production capacity of different types of waste. Favorable range of the C/N ratio is from 20:l to 30:1 to have proper biogas production capacity [31],[33]. The C/N ratio for various types of waste is given in table 9.3.

Table 9.3: Carbon-Nitrogen ratios of some common fermentation materials (approximately).

Materials	Carbon content of material (%)	Nitrogen content of materials (%)	Carbon-nitrogen ration (C/N)
Fresh Cattle Dung	46	0.53	87:1
Fresh pig manure	7.8	0.6	13:1
Fresh Human Waste	2.5	0.85	29:1
Fresh sheep	16	0.55	29:1

dropping			
Dry rice straw	42	0.53	67:1
Fallen leaves	41	1	41:1

9.2 Biogas Plant Design of The System

9.2.1 Energy Demand of A Standard Home

Here a biogas plant be designed for a single house then it will be expanded for the building.

The used loads in the system 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,

0.037 m3 gas is produced from 1 kg cow dung where the waste to water mixing ratio is l: l.

0.07 m3 gas is produced from I kg poultry waste where the waste to water mixing ratio is l:2.

Here a biogas plant be designed for a house then it will be expanded for the building.

The used loads in the system 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 colour TV (100 W) and one refrigerator(150 W)

9.2.2 Design of biogas plant

For the designed system the biogas plant (gas containing capacity of $6m^3$) is essential which needs a poultry farm of about 800 broilers (or layers) or a cow farm of 16 cows. The biogas plant for the system is designed for two options separately. The biogas plant design mainly consists of digester design and design of hydraulic chamber. The digester cross section and the geometrical assumptions are shown in figure 9.3 and table 9.4 respectively.

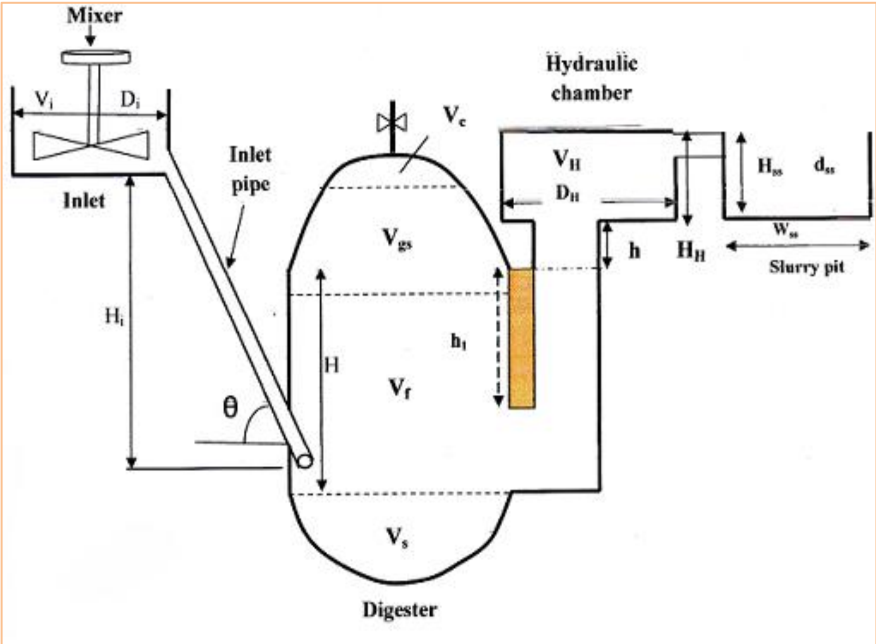


Figure 9.3 : Schematic diagram of biogas plant

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 $=H_H$,Height of the slurry pit = Hss

Width of the slurry pit = Wss ,the inclimed angle of inlet pipe $=\theta$

Table 9.4 : Geometrical assumption for digester design [31]

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

9.2.2.1 Design of biogas plant based on poultry waste

9.2.2.1.1 Volume calculation of digester chamber

Let HRT = 40 days (for temperature 30^0C)

Every broiler or layer hem gives 100gm manure per day.

Total discharge = 800 × 0.1 kg = 80 kg.

TS of fresh discharge = 02 x 80 kg = 16 kg

To make the TS value of 8% for favorable condition some additional water has to mix with fresh discharge. The required water to be added can be calculated by the following way :

8 Kg solid equivalent to 100 kg of influent

16 kg solid equivalent = (100*16)/8=200 kg

Different measurement parameters of digester is shown in figure 9.4

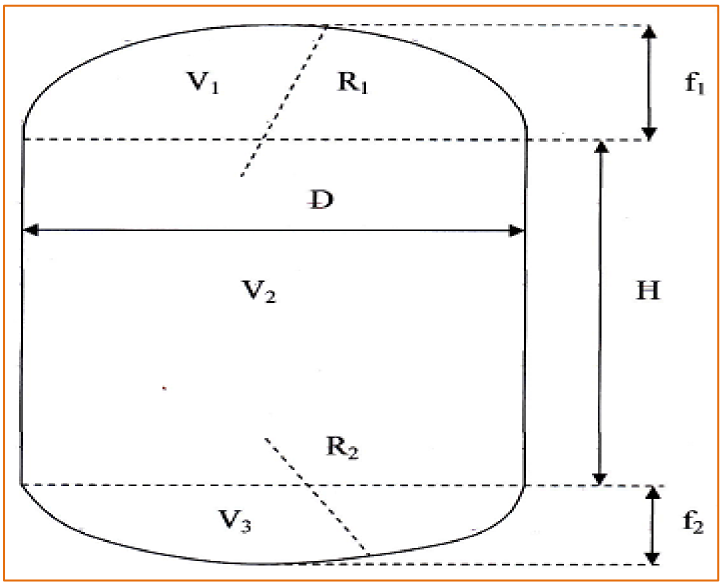


Figure 9.4: Different measurement parameters of digester

So , total influent required ,Q=200 kg per day.

Required water to be added to make TS value 8%=200-80 kg=120 kg

Working volume of digester = Vgs+ Vf

Vgs+ Vf= Q ×HRT=200 kg/day ×40 days

=8000 kg =8 m^3

From geometrical assumption :

Vgs+Vf = 80% V or, 8=0.8V (Putting the value of (Vgs +Vf))

Or,V = 10m^3

And D = 1.3078 $V^{1/3}$ = 2.818m = 2.82 m

Again,

$V3=(3.14\times H\times D^2)/4$ or, $0.3142D^2=(3.14\times D^2\times H)/4$

$H = (4\times 0.3142\times D)/3.14 = 1.13$ m

Now it is found out from assumption as the value of 'D' and 'H' is know

$f_1= D/5=2.82/5=0.564$ m

$f_2 = D/8= 2.82/8=0.3525$ m

$R_1=0.725D=0.725x2.82=2.04$ m

$R_2= 1.0625D=1.0625x2.82=3$m

$V_1=0.0827D^3 =0.0827x(2.82)^3=1.85\ m^3$

$Vc=0.05V=0.05x\ 10\ m^3=0.5\ m^3$

The value of inclined angle of inlet pipe $\theta = 60^\circ$ [33]

9.2.2.1.2 Volume Calculation of Hydraulic Chamber

From assumptions,

$Vc=0.05V=0.5\ m^3$

$Vs= V- (Vgs+Vf+Vc)= 10-(8+0.5)= 1.5\ m^3$

Now the volume of gas storage chamber should be 50% of the gas produced in a day.

So. Vgs = Amount of the daily gas yield = TSx gas production rate per kg TS

= 16 x 0.53 m^3 per kg TS = 5.6 m3

$Vc+ V1 = 0.5+1.85= 2.35\ m^3$

Now, the discharge of outlet should be the same of inlet recharge.

So, outlet discharge, Vdis = 200kg/1000=0.2 m^3

Total volume of the gas staying chamber = Vc+V1+Vdis = 2.35+0.2= 2.55 m^3

Now, the pressure of digester can be calculated.

Let the normal pressure of the digester is Pi=4 kpa or 40 mbar.

Final pressure after gas being stored = Pf

The product gas should have to stay within 2.55 cubic meters volume. so according to Boyle's law,

$$Pi \times (\text{total gas produced} + 2.55) = Pf \times 2.55$$

$$\text{or, } 4 \times (5.6 + 2.55) = Pf \times 2.55$$

$$\text{or } Pf = 12.78 \text{ kPa}$$

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

Pf + Hpg = Hpg +h1pg +hpg

or, h+h1 = P_f/Pg =(12.78*1000)/(1000*9.81)

=1.3 m

Let, height of the hydraulic chamber from digester manure level, h1= 0.3 m

So, height of the hydraulic chamber to digester manure level, h = 1.3 -0.3= 1 m

Now, the volume of the hydraulic chamber is equals to the discharge per day.

If D_H is the diameter of the hydraulic chamber then,

Let H_H = 1m

$$\pi \times (D_H/2)^2 \times H_H = 0.2 \text{ [as 200kg =200 liter]}$$

$$\text{Or,} D_H = \sqrt{(4 \times 0.2/\pi \times H_H)}$$

$$= \sqrt{(0.8/3.1416)}$$

=0.167

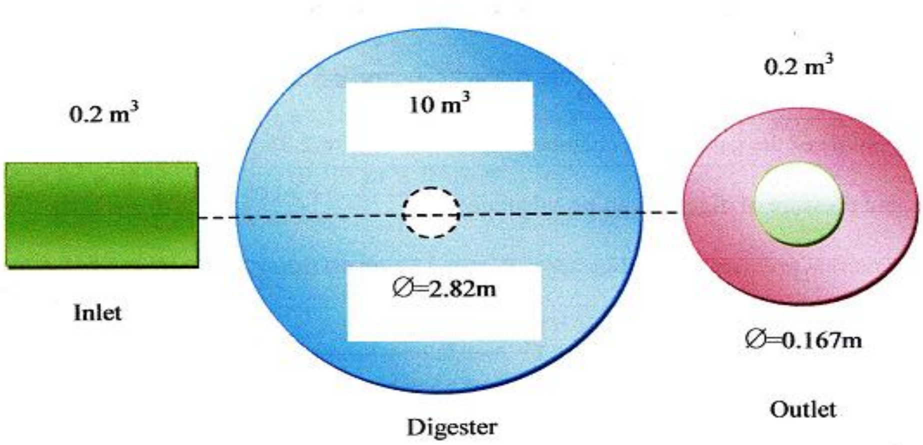


Figure 9.5 : Design layout of digester, inlet and outlet based on poultry waste.

The design parameters (Hss, Wss and dss) of slurry pit should be calculated according to the following rules [33]

a) The height should be double of width.

b) the depth should not more than 1 m because of easy collection of slurry from the pit.

c) Depending on the plant location the design parameters can be altered.

As the calculation of design parameters vary with location so calcualtion of design parameters of slurry pit is not shown here.

9.2.2.2 Design of Biogas Plant Based On Cow Dung

On an average, each cow gives 10 kg cow dung per day [31]

If the number of cow is n then total cow dung = 10n kg

Again practically 0.037 m^3 of bioigas in got from 1 kg of waste [32]

So, total biogas obtained from n numbers of cows

$$= 10n \times 0.037 \text{ m}^3 = 0.37 \text{ n m}^3$$

From each cubic meter biogas 1.4 kWh electricity is obtained

So, from n number of Cows electricity obtained = 0.37 n× 1.4 = 0.518n kWh.

to generate 5.1 kWh electricity the essential number of cows,

0.518n = 5.1 Or, n = 5.1/ 0.518 =9.84 =10

To produce 2 m^3 gases the essential number of cows,

$$0.37n = 2 \text{ or , } n = 2/0.37 = 5.4 \approx 6$$

So, total number of cow = (10+6) = 16

9.2.2.2.1 Volume Calculation on Digester Chamber

Let HRT = 40 days (for temperature 30C)

As from every cow 10 kg manure is obtained per day.

So, total discharge = 16 x 10 kg= 160 kg

Different measurement parameters of digester are depicted in figure 9.4

TS of fresh discharge = 0.16 x 160 kg = 25.36 kg

To make the ts value of 8% for favorable condition some additional water has to mix with fresh discharge. The required waste to be added can be calculated by the following way :

8 kg solid equivalent 100 kg of influent

25.5 kg solid equivalent = (100 *25.6)/8

=320 kg

So, total influent required, Q = 320 kg

Required water to be added to make TS value 8% = 320-160 kg =160 kg

Working volume of digester = Vgs +Vf

Vgs +Vf = Q x HRT = 320× 40 =12800 kg =12.80 m^3

From geometrical assumption

Vgs+Vf = 80%V

Or, 12.8=O8V (Putting the value of (V gs+ Vf))

Or, V = 16 m 3

And D= $1.3078V^{1/3}$ = 3.29m = 3.3 m

Again

V_3 =(3.14×D2× H)/4 or, $0.3142D^3$ = (3.14×D2× H)/4

H = (4×0.3142× D)/3.14 =1.31 m

Now we find from assumption as we know the value of D and H

fi=D/5= 3.3/5=0.66m

f2= D/8=3.3/8=0.4125m

Ri = 0.725D= 0.725×3.3=2.3925m

R2 = 1.0625D=1.0625×3.3=3.50625m

Vi = $0.0827D^3$ $=0.0827\times(3.3)^3$ $=2.97m^3$.

Vc = 0.05V=0.05×$16m^3$ =0.8m3

9.2.2.2 .2 Volume Calculation Of Hydraulic Chamber

From assumptions,

Vc = 0.05V= 0.8 m^3

Vs = V- (Vgs+Vf+Vc)= 16 – (12.8+ 0.8)= 2.4 m^3

Now the volume of gas storage chamber should be 50% of the gas produced in a day.

So, Vgs= Amount of the daily gas yield

= TS × gas production rate per kg TS

= 25.6 × 0.35 m3 per kg TS = 8.96 m^3

Vc + V1 = 0.8+ 2.97 = 3.77 m^3

Now, the discharge of outlet should be the same of inlet recharge.

So, out let discharge

V dis= 320/1000 =0.32 m^3 [as 320 kg = 320 liter]

Total volume of the gas staying chamber =Vc = V1 + V dis= 3.77 + 0.32= 4.09 m^3

Now, the pressure of digester can be calculated. The minimum pressure required to run a generator is at least 4 k Pa.

Let the normal pressure of the digester is Pi= 4 kg a or 40 mbar.

and final pressure after gas being stored = Pf.

The produced gas should have to stay within 1.64 cubic meters volume. So, according to Boyles law,

P × (total gas produced +4.09) = Pf × 4.09

or, 4× (8.96+ 4.09) = Pf × 4.09

or Pf = 12.76 k pa

Let, height of the hydraulic chamber is h. The pressure of the hydraulic chamber should be 12.76 K Pa so that only inler recharge will be discharge

Pf = Hpg= Hpg+ $h_1$pg + hpg

or h+hi =P_f /pg = (12.76 ×1000)/1000*9.81 =1.30 m

Let, height of the hydraulic chamber from digeser manure level, h1 = 0.3m

So, height of the hydraulic chamber, h= 1.8-0.3= Im

Now, the volume of the hydraulic chamber is equals to the discharge per day

If D_H is the diameter of the hydraulic chamber then,

$$\text{Let } H_H = 1\text{m, So, } \pi \left(\frac{D_H}{2}\right)^2 H_H = 0.32 \text{ [as 320 kg} \approx \text{320 liter} = 0.32\ m^3\text{]}$$

$$Or, D_H = \sqrt{\frac{4 \times 0.32}{\pi \times H_H}} = \sqrt{\frac{1.28}{3.1416}} = 0.407\ m$$

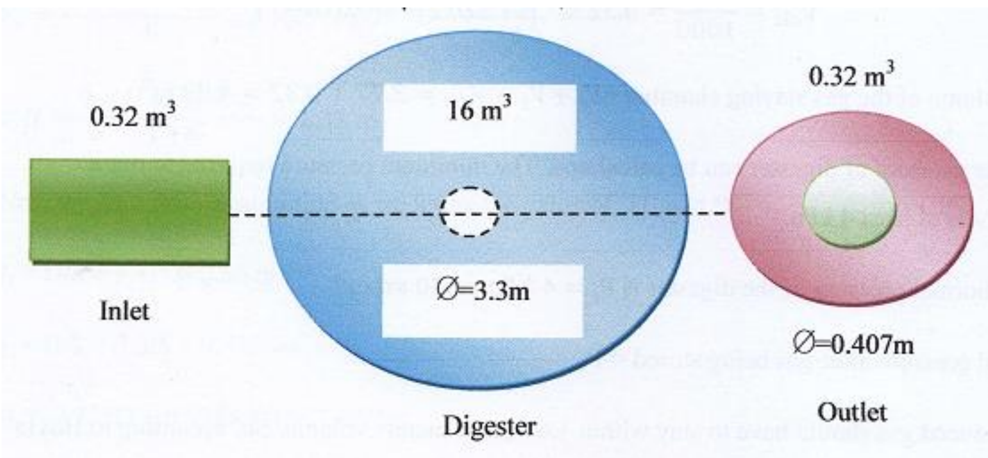


Figure 9. 6: Design layout of digester, inlet and outlet for cow waste

CHAPTER 10

DESIGN OF BIOGAS PLANT FOR A MULTISTORIED BUILDING

10.1 Biogas Plant Design For A Building

10.1.1 Design of Digester

The design parameters are calculated according to the chapter 9. The calculation of the design of biogas plant for a building is given in Appendix. Here three design are shown but one of them will be chosen, where one will be designed for 20 thousand layers and other two will be designed for 15 thousand layers. The design parameters are calculated according to the chapter 9.

10.1.1.1 Design of Digester For 15 Thousand Layers

With the similar calculation of chapter 9 (given in Appendix B) the design layout of biogas plant for 15 thousand layers is shown in figure 10.1.

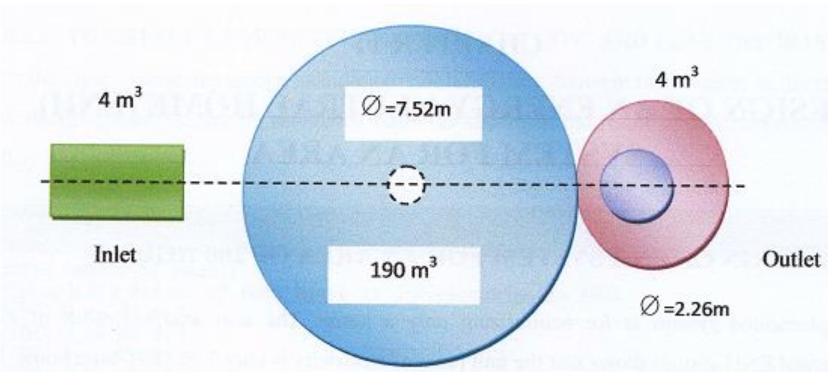


Figure 10.1 :Top view of digester for 15 thousand layers

10.1.1.2 Design of Digester For 20 Thousand Layers

With the similar calculation of chapter 9(given in Appendix B) the design layout of biogas plant for 20 thousand layeres is shown in figure 10.2

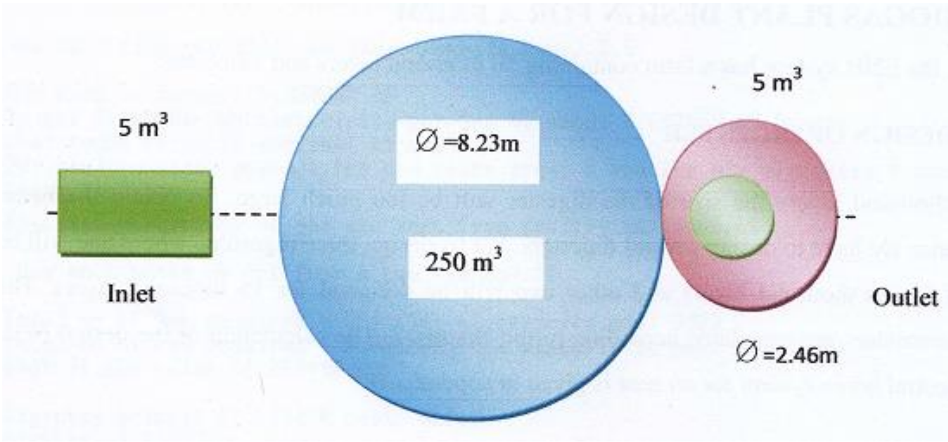


Figure 10.2 : Top view of digester for 20 thousand layers

10.1.1.3 Design of Digester for 140 Cows

With the similar calculation of chapter 9 (given in Appendix B) the design layout of biogas plant for 140 cows is shown in figure 10.3

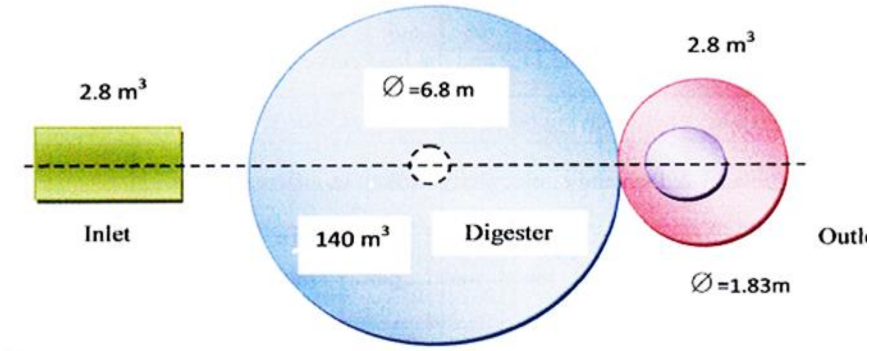


Figure 10.3: Top view of digester for 140 cows

Table 10.1: Electricity Generated from each digester.

Digester no.	Designed for	Gas production capacity (m^3)/ day	Electricity production capacity/day(kw)	Time of electricity supply (Hour)	Unit of electricity (kv/h)
1.	I 5 thousand layer	105	15	10	150
2.	I 5 thousand layer	105	15	10	150
3.	20 thousand layer	140	20	10	200
4.	140 number of cows	78.4	7	10	70

10.2 Cost Calculation for the proposed biogas plant :

I0.2.I Cost Of Digester

Only cost for digester no 1 will be calculated as it is selected for the design.

The cost of a 500 CFT Digester is about 55,000 BDT [35]

The volume of digester no.1 is 190 m^3 = 190 × $(3.28)^3$ CFT = 6,704.6 CFT

So, The cost of Digester = (55,000/500) × 6,704.6 BDT=7,37,506 BDT

Volume of hydraulic chamber and inlet recharge chamber = 2× 4× 3.28^3 CFT= 282 CFT

So, cost of hydraulic chamber and inlet recharge chamber = 282 × 110= 31,020 BDT

Total cost of digester : 7 ,37,506+ 3l,020 BDT =7,68,526 BDT.

10.2.2 Cost Of Purification And Units And Pipe Line

Cost of purification Unit=10,000 BDT.

Pipe line and others = 5,000 BDT.

10.2.3 Cost Of Generator [36],[37]

Cost of 10 kW generator: 1,70,000

Subtotal Cost of Plant =(7,68,526+1,70,000+15,000) BDT = 9,53,526 BDT.

10.2.4 Transmission Line Cost

Let, Transmission line Cost is 0.5% of the total plant cost.

So, Transmission line cost =9,53,526 x0.005 = 4767.63 BDT.

10.2.5 Total Cost of The System

Total cost of the system = (9,53,526+4,768)BDT =9,58,294 BDT.

10.3 Cost Analysis

electricity consumption per day = 10 kW ×15h =150 kWh

Income per month = 150 kWh × 30 ×9.86 =44,370

Income per year = (44,370 x 12) BDT. = 532440 BDT.

Repairing cost of transmission line per year = 12,500 BDT.

Net income per year = (532440- 12500) BDT. = 519940 BDT .

Income per 20 years = (519940x20) BDT = 1,03,98,800 BDT.

Overhauling Cost of Generator for 20 years

Overhauling of a generator is required after 10,000 hours of operation which is called top overhauling. The cost of top overhauling is about l5% of the generator cost. Another overhauling has to be done after further 10,000 hour operation which is called major overhauling. Cost of major overhauling is about 50% of the generator cost [46].

Overhauling cost of generator

Operating time will be (15 × 30× 12 × 20)=1,08,000 hours, if operates in 20 years. So six times top overhauling and 4 times major overhauling have to be done.

Top overhauling cost fo one time = 15% of 1,70,000 = 25,500 BDT.

Total top overhauling cost = (25,500x6) BDT. = 1,53,000 BDT.

Major overhauling cost for one time = 50% of 1,70,000=85,000 BDT.

Total overhauling cost for generator = (85,000x4) BDT. = 3,40,000 BDT.

Total overhauling cost of generator = (153000 +340000) BDT

= 4,93,000

Repairing cost = 10000

Total operating cost = repairing cost + overhauling cost of generator

=10000 + 493000

= 503000

So net income considering the overhauling cost of generator after 20 years,

=1,03,98,800-5,03,000

= 98,95,800

Net income per year : (98,95,800/20) BDT = 4,94,790 BDT.

Total investment will be come out within = (9,58,294/ 4,94,790) years

=1.936

≈2

Total investment will be come out within 2 years

Electricity produced in a day = 10 kW × 15 h

=150 kWh

Total electricity produced in 20 years =150 × 30 ×12 ×20 kWh =10,80,000 kWh

Total cost = 503000+ 958294 =14,61,294 BDT.

Per Unit Cost = 1461294 / 1080000 BDT = 1.35 BDT.

The analysis is done for a life time of 20 years.

CHAPTER 11

RESULTS AND DISCUSSIONS

11.1 Introduction

In this thesis, a cost effective and efficient grid connected hybrid power system has been designed for a fourteen storied building situated at Mirpur Cantonment, Dhaka, Bangladesh. This design may work as a model of hybrid power system installation in the densely populated cities. By collecting the geographical data and components specifications, this system is designed. The average output power and cost have been calculated for both solar and bio energy. Finally, this model is optimized comparing different types of system components and connection possibilities. The final results and corresponding discussions are presented in this chapter.

11.2 Results

Load Analysis:

By surveying the selected building, it is found that the total connected load is 230 kW(30 KW for lift) and the maximum consumption load in summer and winter is 150 & 90 kW respectively.

Number of Panels:

The area available for installing solar panel excluding the used space and loss area has been found as 5400 sft. The tilt angle of our site is 21 degree. Using the tilt angle and dimensions of the selected panel, separation between two modules in a single array is 6 inch and that of two consecutive arrays 6 ft 10 inch. To avoid shading effect the minimum open space between two arrays is 20 inch. Finally, from the system arrangement, the number of panels has been found as 230 panels.

Generators:

For biogas plant considering the environmental effect and availability of raw materials one 10 kW gas generator has been selected for the **"Polash"** building, although there is more free space .The slurry of the system can be used in land as fertilizer.

Average Output Power:

The average incident solar radiation at this site is 0.191 KW/m^2. For the site 200 Wp mono crystalline solar module has been selected and its calculated efficiency is 15.6%. Peak output power of the designed system is 46kW. Considering the derated factor and neglecting the temperature effect, the average output power has been calculated as 7.03 kW. Assuming the average hours of operation in a day as 12 hrs, the total hours of operation in a year is 4380 hrs/yr. So, the average solar energy production is 30,792 kWh/yr.

Output Power of other types of modules:

The calculated efficiency of 200 Wp polycrystalline module and thin-film module are found to be 13.5% and 11.1% respectively and average output powers of the whole system are 6.26 Kw and 5.335 Kw respectively.

Installation Cost of Different types of Modules:

The installation cost or capital cost of the system using mono-crystalline solar panels is 64, 53,000 Taka. Those for systems using poly-crystalline and thin-film solar panels are 44,37,420 Taka and 46,96,380 Taka respectively.

Operation and Maintenance Cost of Different types of Modules:

The operation and maintenance cost of the system using mono-crystalline solar panels is 1,93,590 taka/yr. Those for systems using poly-crystalline and thin-film solar panels are 1,33,123 taka/yr and 1,40,891 taka/yr respectively.

Savings from Different Types of Modules:

The monetary savings by selling electricity to the grid from a system using mono-crystalline solar panels is 3,03,609.12 taka/yr. Those for systems using poly-crystalline and thin-film solar panels are 2,70,349.36 taka/yr and 2,30,401.578 taka/yr respectively.

Result of including solar panel cooling

1. Increase in efficiency

2.3% increase in efficiency by a 10.9°C decrease in temperature can be made using the heat absorbing methodology.

2. Increase in output power

3. Economic outcome

11.3 Discussions

i. Power Generation:

In output power calculation, comparison was done among mono-crystalline, poly-crystalline and thin film solar panel's output. Calculations show that mono-crystalline silicon solar panels have the highest efficiency, but poly-crystalline and thin film solar panels are less efficient. Their efficiencies are 15.6%, 13.5% and 11.1% respectively. As a result, the first one gives the highest output power. The average output power of this system using mono-crystalline solar panels is 7.03 Kw. The average output power for poly-crystalline and thin film solar panels are 6.26 Kw and 5.335 respectively. So mono-crystalline solar panels are the best option among these three considering maximum power .

ii. **Cost of the solar system:**

Through the process of survey the market price of different types of solar panels is determined to evaluate the system cost. The cost calculation chapter shows that system mono-crystalline solar panels have the highest installation cost among the three types of solar panels. The poly-crystalline and thin film solar panels are much cheaper than the mono-crystalline ones. The operation and maintenance cost of solar power system varies proportionately with the capital cost. Since the mono-crystalline solar panels have the highest capital cost, they also have the highest operation and maintenance cost. So if anybody has a limited budget and are looking for a cheaper option, they can select either poly-crystalline or thin film solar panels.

Another important thing is though the installation cost is very high, it would become much lesser when the government will give subsidies (which are also given to the traditional power plants) and the rest will be divided among the 52 flat-owners of the building.

iii. **Revenue earned by selling solar power:**

Though the installation cost is high for this system, a handsome profit can be earned each year by selling the power to the grid. Since the mono-crystalline solar panels have the highest output power, they can earn the highest profits compared to the other types of solar panels. They can earn 3,03,609.12 taka per year which is greater than revenue earned by poly-crystalline and thin film solar panels.

iv. **Temperature Effect:**

Normally mono-crystalline solar panels have the highest efficiency among all types of solar panels currently existing in the market that are used for power generation purpose. Their efficiency is around 20% [46]. But in our calculation in chapter 5, it was only 15.6%. The result is lower because the panels lose their efficiency as the temperature increases above STC (25ºC). Since calculation of efficiency and power were done neglecting the temperature effect. So, in order to increase the efficiency, the panels must be installed in such a way as to cool down the panels by some cooling method during the hottest hours of the day.

v. Optimization of solar system cooling:

As temperature of the panels were decreased by using water cooling methodology. Besides this hot water from the cooling system can be supplied to the apartments instead of using geyser which reduces cost.

CHAPTER 12
CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORKS

12.1 Conclusions

a. The thesis is a study of commercial application of grid-connected hybrid power system for a high rise building on densely populated cities. Calculation of output power and cost of a solar system installed at the unused space of the rooftop of a multistoried apartment is shown. Though output power from individual building is small, significant power can be drawn from the system if it is installed in a large number of buildings. Comparison of the output power and cost for different types of solar panels e.g. mono-crystalline, poly-crystalline and thin film solar panels were done. In this way, the designed power system can go a long way to reduce the present power crisis of Bangladesh.

b. In this thesis 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. Grid-connected system does not require batteries. So it is much more reliable than the off-grid solar system.

c. A very simple but efficient and cost effective biogas electric generation system has been integrated to the building as well. This system provides a handsome amount of power to the grid through the hybrid system.

12.2 Suggestions Suggestions For Future Works

1) Implementation of solar panels to the façade of southern portion of the building can increase the electricity generation.

2) Biogas can be used for cooking system of whole building by which huge amount of natural gas can be saved.

3) The idea of incorporating biogas technique in urban area can be unique step to energy solution way.

4) This hybrid energy system can be implemented instead of diesel generator power generation system during load shedding.

5) This system can be a great step towards the smart energy system. Smart energy system includes the feature of renewable energy system and the management of its intermittency.In Bangladesh, the existing energy system is not a smart energy system. If other features of the smart energy system is added to this existing system, our hybrid system design can be a glaring example of Smart Energy.

REFERENCES

1. http://www.renewableenergyworld.com

2. http://purkrt.net/p/Solar_land_area.png

3.http://www.bpdb.gov.bd/bpdb/index.php?option=coni_content&view=article&1d=150&Item1d=16; retrieved on 19/1212010

4. Ulrike Jahn and Wolfgang Nasse; "Performance analysis and reliability of Grid-connected PV systems in lEA countries", 2003.

5. Prof. Dr. Arninul Hogue, " Smart Energy System Future of Distribution Grids, storage and Hybrid Systems in Bangladesh Perspective", 2012

6.ADOL F GOETZBERGER AND VOLKER HOFFMANN, Photovoltaic Solar Energy Generation: Springer-Verlag Berlin Heidelberg, 2005.

7.RYAN MAYFIELD, Photovoltaic Design and Installation: Wiley Publishing, Inc, 2010.

8.http://www.leonics.com/supp0rtiarticle2_12yarticles2_12Len.php; retrieved on 19/12/2010.

9.http://www.jcmiras.net/surge/p29.htm; retrieved on 19/12/2010.

10.http://www.solar-estimate.org/index.php?verifycookie=1&page=solar calculations&subpage=&external_estimator=; retrieved on 2/2/2013.

11.MUKUND R. PATEL, "Wind and Solar Power Systems", 2nd Edition, 2006.

12. http:///www.amsolar.com/home/arnr/smartlist_l /solar_products_for_rvs.html; retrieved on 2011

13.Kossmann W., Ponitz U., -Bioaas Digest-, information and Advisory Service on Appropriate, Technology (ISAT), vol. 1 pp. 04.

14. Milono P., Linciaiati T. and Aman S., "Bioaas production from agricultural organic residues", The First ASEAN Seminar-Workshop on Biogas Technology, Working, Group on Food waste Materials, pp. 52-65, 1981.

15. Cheremisinoff N. P., "Landfill operations and gas enemy recovery", Handbook of Solid Waste Management and Waste Minimization Technologies, pp 109-117. Elsevier, 2003.

16. penis A. and purko PE., °pally Waste Anaerobic Digestion Handbook", Environmental Fnergy Company, June, 2001.

17. Audra A. 0. and Aryati V. D., "Biogas production using anaerobic biodigester from cassava starch effluent with ruminant bacteria as hiocatalyst" M. Sc. thesis, chemical engineering department, Diponegoro University, Semarang, pp. 14-16, January 19, 2010.

18.http://en.wikipedia.org/wiki/Capital_cost; retrieved on 14/3/2013.

19.www.alibaba.com; retrieved on 16/10/2011.

20.http://www.investorwords.com/4181/replacement_cost.html; retrieved on 19/3/2013.

21.http://www.unplugelectric.com/howsavings retrieved retrieved on 21/4/2013

22.http://greenzu.com/solar-pv-inverter; retrieved on 21/4/2013

23.http://en.wikipedia.org/wiki/Operating_expense; retrieved on 21/4/2013

24.http://www.harbornet.com/sunflowed; retrieved on 21/9/2013

25.http://bill.wrytestuff.com/svva139552.htm; retrieved on 21/4/2011.

26.http://www.ergon.com.au/your-home/accounts—and—billing/electricity-prices#content-id¬58257; retrieved on 16110/2011.

27.http://www.australianpowerandgas.com.au/energyefficiency/renewableenergyandbuybac kplans; retrieved on 16/10/2011.

28.wwvv.bpdb.gov.bd; retrieved on 21/9/2011.

29."HOMER", a software for micro power optimization modeling.

30."Improved Efficiency Solar Cells with Forced Cooling Water; Rahmat Subarkah, Belyamin.

31. Biogas-Project, Training material of LGED (Local Government Engineering Development), Bangladesh. 1999.

32.Islam K. U., Senior Advisor, Sustainable Energy for Development (SED), GTZ (Deutsche Gesellschaft fur Technische Zusammenarbeit), Gulshan 2, Dhaka 1212, Bangladesh.

33. Gofran M. A., Asrafuzzaman M., "IDCOL Biogas Plant Construction Mannual", 1DCOL Infrastructure Development Company Limited, Bangladesh, April 2007.

34. Booklets and Research materials of Biogas Training Centre (BRC), Chendu, Sichum, China.

35. Rahman Renewable Energy Co. 1.td, Local Office of 1DCOL (Infrastructure Development Company Limited). Joydebpur. Gajipur. Ilangladesh, December 2010.

36.Sorkaar A. A., Service Engineer, Bangla Power Company Ltd., Chittagong branch, Bangladesh, 2010.

37.All M. A., Managing Director, INTRACO GROUP, 69, Suhrawardy

Avenue, Baridhara, Dhaka —1212, Bangladesh.

APPENDIX A

Specifications of Equipments

- Specifications of Mono-crystalline Silicon Solar Panel (Provided By The Electro Solar Company)

Specialty :

1. High Conversion Efficiency based on leading innovative photovoltaic technologies
2. High reliability with guaranteed ± 3% power output tolerance, ensuring return on

   investment
3. Withstand high wind-pressure and snow load and extreme temperature variation.

Quality and Safety :

I. 20-year power output transferrable warranty

II. Rigorous quality control meeting the highest international standards

III. ISO 9001:2008 (Quality Management system) certified factories manufacturing World class products

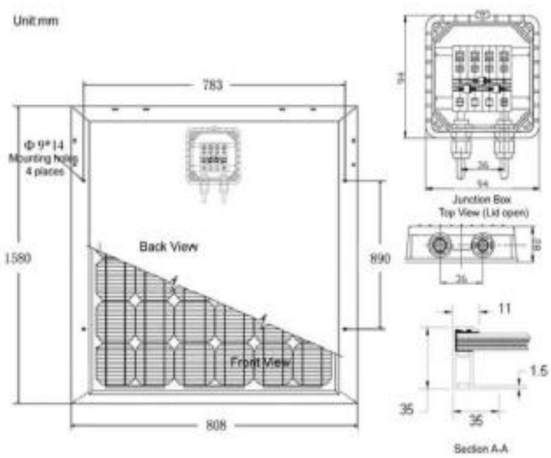
Electrical Characteristics :

Maximum power at STC （Pmax）	200W
Optimum operating voltage （Vmp）	34.4V
Optimum operating current （Imp）	5.81A
Open-circuit voltage （Voc）	43.2V
Short-circuit current （Isc）	6.5A
Short-circuit current temperature coefficient	（0.065±0.015）%/℃
Open-circuit voltage temperature coefficient	-（80±10）mV/℃
Peak power temperature coefficient	-（0.5±0.05）%/℃
NOCT (Air 20℃; Sun 0.8kW/m wind 1m/s)	47±2℃
Operating temperature	-40℃ to 85℃
Maximum system voltage	1000V DC
Power tolerance	±3%
STC: Irradiance 1000W/m², Module temperature 25℃, AM=1.5	

Features :

- Nominal 24V DC for standard output.
- High efficiency.
- Outstanding low-light performance.
- High transmission tempered glass.
- Rugged design to withstand high wind pressure and snow load, easy installation.
- Aesthetic appearance.
- Design to meet unique demand of customer.
- 20 year module output warranty.

Dimension



Characteristics

Specification	
Cell	Mono-crystalline silicon solar cells
No. of cell and connection	72（6×12）
Dimension of module	1580mm×808mm×35mm
Weight	20kg
Specifications are subject to change without notice at any time.	

- **Specifications of Grid-Connected Solar Inverter**

Product Details:

Quick Details:

i. Place of Origin: Zhejiang, China (Mainland)
ii. Brand Name: TRESS
iii. Model Number: TLS-20KTS
iv. Type: grid connected solar inverter
v. Colour: green,orange,silvery
vi. name: solar inverter
vii. shape : optional
viii. Application: solar energy system

Packaging & Delivery:

Packaging Details: Honeycomb box printed with save marks,if necessary ,pallet is needed in order to make the save delivery

Delivery Detail: 10~25days

Specifications

1.Solar inverter with ISO,CE certificate,VDE0126 from INTERTEK

2.More than 10years production experience

3.Pure sine wave

Features :

i. Wide DC input voltage range
ii. DSP controller
iii. High efficiency by using advanced IGBT and IPM
iv. MPPT(Maximum power point tracking) technology
v. High efficiency
vi. In accordance with international standards
vii. Quick and easy installation
viii. Operation parameters can be adjusted via LCD and keys
ix. The perfect protection function
x. Designed to suitable for critical grid environment

Technical Data

Model		TLS 20KTS
DC Input	MPPT DC Voltage Range	DC200 ~ 850V
	Rated DC Voltage	620 V
	Control System	MPPT
AC Output	Rated Output Power	20kw
	Rate voltage	AC380V± 38V
	Normal Grid Frequency	50/60Hz(Grid frequency)
	Phases	3 phase 4 wire
	Power Factor	> 0.95
	Current THD	At rated power and in the sine wave < 3. 5%
	Control System	PWM
	Anti-islanding	≤0.5 sec
	Max. Efficiency	97%

	Euro Efficiency	96.4%
Structure	Protection Class	IP20
	Cooling system	Natural cooling
	Noise	< 60dB
	Data Interfaces	External RS232C/RS485
	Display	LCD
	Packing Dimensions (W*H*D)	560*760*675mm
	Net weight	60 kgs
	Gress weight	63 kgs
Protection	Inverter	Input over voltage, output short circuit, overheat, output DC component.
	Grid	Anti-islanding, over/under voltage of grid, over/under frequency of grid.
Environment	Environment	No corrosion gas, flammable gas, oil mist, dust etc.
	Operation temperature	-10 °C ~40 °C (50 °C)
	Stored temperature	-20 °C ~ 65 °C
	Relative humidity	0~100% (Do not wet with dew)

- **Specification of PV combiner Box**

Quick detailes:

1. **Place of Origin:** Hubei China (Mainland)
2. **Brand Name:** TRESS
3. **Model Number:** TLS
4. **Type:** Combiner Box

5. **Certification:** CE ;ISO
6. **Item:** PV Combiner Box
7. **IP:** 65
8. **Input arrays:** optional
9. **Original:** china
10. **Details:** customized

Packaging & Delivery :

Packaging Detail: cartons, pallet is needed in order to make the safe delivery

Delivery Detail: 5-30days

Features:

1. Simultaneous access to multiple photovoltaic arrays; each channel current up to 10A; to meet the needs of different users.

2. With reliable, lighting and surge protection, solar photovoltaic DC high voltage lighting protection device, all with positive doubt negative lightning protection function.

3. Wide range DC voltage input; DC high voltage circuit breaker with professional pressure range of 200~900Vdc, safe and reliable.

4. 6 groups can simultaneously access PV array.

5. The port has a water resistant.

6. DC with high voltage fuses and circuit breakers were two security devices.

7. Each array can be optional current monitoring on each channel of the current measurement and monitoring.

8. Wall structure with outdoor rain shell protection grade to IP65, to meet the application requirements for outdoor installation.

9. Installation and maintenance simple, convenient, long service life

- **Specifications of Mounting Structure**

Quick Detailes:

i. Place of Origin: Zhejiang China (Mainland)
ii. Brand Name: Chuangyuan
iii. Model number: CY-G04
iv. Type : Solar Bracket
v. Application: Solar Panel Installation
vi. Pipe Material: Aluminum Alloy
vii. Color: Natural
viii. Item :Solar Panel Bracket Of Flat Roof

Specifications

a. All the support structural elements are hot dipped galvanized to guarantee the lifetime.

b. All the support structural elements are hot dipped galvanized to guarantee the lifetime of support.
c. Adopt high-quality steel pipe and other excellent section bars to ensure sufficient strength of support.
d. Installation area of solar panel components in design is 2.5-100m2.
e. Wind load resistance of support in design is 216km/h.
f. The ground support system which is convenient for installation and maintenance free has developed into the general solar panel installation system suitable for open ground outdoor. The unique innovative aluminum alloy track, Z-shaped card and pipe cap can be used to connect multiple units conveniently and simply to meet the actual requirements on various grounds for installation. It is suitable for installation and application of solar panels with and without frame and is mainly used in large-scale solar power station with the advantages of low cost, rapid installation and stability.

Technical characteristics:

Installation site: outdoor

Installation angle: It is based on customers' requirements

Installation height: it is based on customers' requirements

Wind resistance: 60m/s

Snow load: 14KN/m^2

Solar panel type : with or without frame

Components: horizontal or vertical arrangement

International criteria: eligible

Support track: aluminum alloy extrusion

Color: natural

Quality warranty : 10 years

- **Specifications of Filter**

Product Details :

Quick Details

Places of Origin: China (Mainland)

Model Number: FT330FW series

Type: EMI Filter

Transfer Function : Low Pass

Specifications:

a. Designed for PV Photovoltaic
b. Guarantee the quality of the grid current
c. CE,ROHS

Product Features

i. AC three phase filters used in all gird-tied inverter systems to protect environment from electromagnetic pollution.

ii. Effectively get rid of the electromagnetic pollution of the output current of the inverter, guarantee the quality of the grid current.
iii. Prevention of the electromagnetic interference of inverter towards controller and solar panel.
iv. Prevention of the electromagnetic interference of inverter towards grid-tied equipments.

APPENDIX B

DESIGN OF DIGESTER FOR 15 THOUSAND LAYERS:

VOLUME CALCULATION OF DIGESTER CHAMBER:

Let HRT = 40 days (for temperature 30°C)

We know from every layer 100 gm manure is obtained per day.

Total discharge=$15000 \times 0.1\ kg = 1500\ kg$

TS of fresh discharge = $0.2 \times 1500kg = 300\ kg$

To make the TS value of 8% for favorable condition we have to mix some additional water with fresh discharge. The required water to be added can be calculated by the following way,

8 kg solid equivalent 100 kg of influent

$$\therefore \text{ 300 kg solid equivalent} = \frac{100 \times 300}{8} = 3750\ kg$$

So, total influent required, Q= 3750 kg per day.

Required water to be added to make TS value 8% =$3750 - 1500kg = 2250\ kg$

Working volume of digester= $V_{gs} + V_f$

$$V_{gs} + V_f = Q \times HRT = 3750\frac{kg}{day} \times 40\ days = 150000\ kg = 150\ m^3$$

From geometrical assumption:

$V_{gs} + V_f = 80\%V$

Or, 150 = 0.8V (Putting the value of $(V_{gs} + V_f)$)

Or, $V = 187.5\ m^3 \approx 190\ m^3$

And $D = 1.3078V^{1/3} = 7.518\ m \approx 7.52\ m$

Again,

$$V_3 = \frac{3.14 \times D^2 \times H}{4}$$

$$or, 0.3142D^3 = \frac{3.14 \times D^2 \times H}{4}$$

$$\therefore H = \frac{4 \times 0.3142 \times D}{3.14} = 3\ m$$

Now from assumption the following values are calculated as the value of 'D' and 'H' are known:

f_1= D/5 =7.52/5 = 1.5 m

f_2= D/8=7.52/8 = 0.94 m

R_1 = 0.725D = 0.725×7.52 = 5.452 m

R_2 = 1.0625D = 1.0625×7.52 = 8 m

V_1= $0.0827D^3$= $0.0827\times(7.52)^3$= 35.17 m^3=35.2 m^3

V_c= 0.05V= 0.05×190 m^3= 9.5 m^3

The value of inclined angle of inlet pipe, $\theta = 60^0$ [40]

VOLUME CALCULATION OF HYDRAULIC CHAMBER

From assumptions,

$V_c = 0.05V = 9.5\ m^3$

$V_s = V - (V_{gs} + V_f + V_c) = 190 - (150 + 9.5) = 30.5\ m^3.$

Now the volume of gas storage chamber should be 50% of the gas produced in a day.

So, $V_{gs} = Amount\ of\ the\ daily\ gas\ yield$

$= TS \times gas\ production\ rate\ per\ Kg\ TS$

$= 300 \times 0.35 = 105\ m^3$

$V_c + V_1 = 9.5 + 35.2 = 44.7\ m^3 \approx 48\ m^3$

Now, the discharge of outlet should be the same of inlet recharge.

So, out let discharge

$$V_{dis} = \frac{3750}{1000} = 3.75\ m^3 \approx 4m^3\ (\ as\ 3750\ kg\ \approx 3750\ liter)$$

Total volume of the gas staying chamber $= V_c + V_1 + V_{dis} = 48 + 4 = 52\ m^3$

Now, we can calculate the pressure of digester.

Let the normal pressure of the digester is $P_i = 4\ kPa$.

and final pressure after gas being stored $= P_f$

The produced gas should have to stay within 52 cubic meters volume. So, according to Boyle's law,

$$P_i \times (total\ gas\ produced + 52) = P_f \times 52$$

$$Or,\ P_i \times (105 + 52) = P_f \times 52$$

$$Or,\ P_f \times 52 = 4 \times (105 + 52)\ \ Or, P_f = 12.08\ kPa$$

Let, height of the hydraulic chamber is h. The pressure of the hydraulic chamber should be 12.08 kPa so that only the inlet recharge will be discharge.

$$P_f + H\rho g = H\rho g + h_1\rho g + h\rho g$$

$$Or, h + h_1 = \frac{P_f}{\rho g} = \frac{12.08 \times 1000}{1000 \times 9.81} = 1.23\ m$$

Let, height of the hydraulic chamber from digester manure level, $h_1 = 0.23\ m$

So, height of the hydraulic chamber, $h = 1.23 - 0.23 = 1m$

Now, the volume of the hydraulic chamber is equal to the discharge per day.

If D_H is the diameter of the hydraulic chamber then, and $H_H = h = 1$ m

$$\pi\left(\frac{D_H}{2}\right)^2 h = 4$$

$$Or, D_H = \sqrt{\frac{4\times 4}{\pi \times H_H}} = \sqrt{\frac{16}{3.1416\times 1}} = 2.26\ m$$

DESIGN OF DIGESTER FOR 20 THOUSAND LAYERS

HRT =40 days (for temperature 30°C)

We know from every layer 100gm manure is obtained per day.

Total discharge=$20{,}000 \times 0.1\ kg = 2000kg$

TS of fresh discharge=$0.2 \times 2000kg = 400kg$ [Table 7.2]

To make the TS value of 8% for favorable condition we have to mix some additional water with fresh discharge. The required water to be added can be calculated by the following way,

8 kg solid equivalent 100 kg of influent

$$\therefore\ 400\ \text{kg solid equivalent} = \frac{100\times 400}{8} = 5000\ kg$$

So, total influent required, Q = 5000 kg.

Required water to be added to make TS value 8% = $5000 - 2000kg = 3000\ kg$

Working volume of digester = $V_{gs} + V_f$

$$V_{gs} + V_f = Q \times HRT = 5000\frac{kg}{day} \times 40\ days = 200000\ kg = 200\ m^3$$

From geometrical assumption:

$V_{gs} + V_f = 80\%V$

Or, 200=0.8V (Putting the value of $(V_{gs} + V_f)$)

Or, $V = 250\ m^3$

And $D = 1.3078V^{1/3} = 8.23\ m$

Again,

$$V_3 = \frac{3.14 \times D^2 \times H}{4}$$

$$or, 0.3142D^3 = \frac{3.14 \times D^2 \times H}{4}$$

$$\therefore H = \frac{4 \times 0.3142 \times D}{3.14} = 3.3\ m$$

Now we find from assumption as we know the value of 'D' and 'H'

$f_1 = D/5 = 8.23/5 = 1.65m$

$f_2 = D/8 = 8.23/8 = 1.02m$

$R_1 = 0.725D = 0.725 \times 8.23 = 6m$

$R_2 = 1.0625D = 1.0625 \times 8.23 = 8.74m$

$V_1 = 0.0827D^3 = 0.0827 \times (8.23)^3 = 46.1\ m^3$

$V_c = 0.05V = 0.05 \times 250\ m^3 = 12.5\ m^3$

The value of inclined angle of inlet pipe, $\theta = 60^0$ [40]

Volume calculation of hydraulic chamber:

From assumptions,

$V_c = 0.05V = 12.5\ m^3$

$V_s = V - (V_{gs} + V_f + V_c) = 250 - (200 + 12.5) = 37.5\ m^3$.

Now the volume of gas storage chamber should be 50% of the gas produced in a day.

So, $V_{gs} = Amount\ of\ the\ daily\ gas\ yield$

$= TS \times gas\ production\ rate\ per\ Kg\ TS$

$= 400 \times 0.35 = 140\ m^3$

$V_c + V_1 = 12.5 + 46.1 = 58.6\ m^3 \approx 60\ m^3$

Now, the discharge of outlet should be the same of inlet recharge.

So, out let discharge

$$V_{dis} = \frac{5000}{1000} = 5\ m^3 (\ as\ 5000\ kg\ \approx 5000\ liter)$$

Total volume of the gas staying chamber $= V_c + V_1 + V_{dis} = 60 + 5 = 65\ m^3$

Now, we can calculate the pressure of digester.

Let the normal pressure of the digester is $P_i = 4\ kPa$.

and final pressure after gas being stored = P_f

The produced gas should have to stay within 65 cubic meters volume. So, according to boyle's law,

$$P_i \times (140 + 65) = P_f \times 65$$

$$Or, P_f = \frac{4 \times 205}{65} = 12.61\ kPa$$

Let, height of the hydraulic chamber is h. The pressure of the hydraulic chamber should be 12.61 kPa so that only the inlet recharge will be discharge.

$$P_f + H\rho g = H\rho g + h_1\rho g + h\rho g$$

$$Or, h + h_1 = \frac{P_f}{\rho g} = \frac{12.61 \times 1000}{1000 \times 9.81} = 1.285\ m$$

Let, height of the hydraulic chamber from digester manure level, $h_1 = 0.23\ m$

So, height of the hydraulic chamber, $h = 1.285 - 0.23 = 1.05m = H_H$

Now, the volume of the hydraulic chamber is equals to the discharge per day.

If D_H is the diameter of the hydraulic chamber then,

$$\pi\left(\frac{D_H}{2}\right)^2 h = 5$$

$$Or, D_H = \sqrt{\frac{4 \times 5}{\pi \times H_H}} = \sqrt{\frac{20}{3.1416 \times 1.05}} = 2.46\ m$$

DESIGN OF DIGESTER FOR 140 COWS

HRT =40 days (for temperature 30°C)

We know from every layer 10 kg manure is obtained per day.

Total discharge=140×10 kg = 1400 kg

TS of fresh discharge= (0.16×1400) kg = 224 kg

To make the TS value of 8% for favorable condition we have to mix some additional water with fresh discharge. The required water to be added can be calculated by the following way,

8 kg solid equivalent 100 kg of influent

$$\therefore\ 224\ \text{kg solid equivalent} = \frac{100 \times 224}{8} = 2800\ kg$$

So, total influent required, Q= 2800 kg.

Required water to be added to make TS value 8% =2800-1400 kg = 1400 kg

Working volume of digester= $V_{gs} + V_f$

$$V_{gs} + V_f = Q \times HRT = 2800\frac{kg}{day} \times 40\ days = 112000kg = 112\ m^3$$

From geometrical assumption:

$V_{gs} + V_f = 80\%V$

Or, 112=0.8V (Putting the value of $(V_{gs} + V_f)$)

Or, $V = 140\ m^3$

And $D = 1.3078V^{1/3} = 6.8\ m$

Again,

$$V_3 = \frac{3.14 \times D^2 \times H}{4}$$

$$or, 0.3142D^3 = \frac{3.14 \times D^2 \times H}{4}$$

$$\therefore H = \frac{4 \times 0.3142 \times D}{3.14} = 2.72\ m$$

Now from assumption the following values are calculated as the value of 'D' and 'H' are known:

f_1 = D/5 = 6.8/5 =1.36 m

f_2 = D/8 = 6.8/8 = 0.85 m

R_1 = 0.725D = 0.725×6.8 = 4.93 m

R_2 =1.0625D =1.0625×6.8 = 7.23 m

V_1 = $0.0827D^3$ = $0.0827\times(6.8)^3$ =26 m^3

V_c = 0.05V = 0.05×140 m^3 = 7 m^3

The value of inclined angle of inlet pipe, $\theta = 60^0$ [40]

Volume calculation of hydraulic chamber:

From assumptions,

$V_c = 0.05V = 7\ m^3$

$V_s = V - (V_{gs} + V_f + V_c) = 140 - (112 + 7) = 21\ m^3.$

Now, the volume of gas storage chamber should be 50% of the gas produced in a day.

So, $V_{gs} = Amount\ of\ the\ daily\ gas\ yield$

$= TS \times gas\ production\ rate\ per\ Kg\ TS$

$= 224 \times 0.35 = 78.4\ m^3$

$V_c + V_1 = 7 + 26 = 33\ m^3$

Now, the discharge of outlet should be the same of inlet recharge.

So, outlet discharge

$$V_{dis} = \frac{2800}{1000} = 2.8\ m^3(\ as\ 2800\ kg\ \approx 2800\ liter)$$

Total volume of the gas staying chamber $= V_c + V_1 + V_{dis} = 33 + 2.8 = 35.8\ m^3$

Now, we can calculate the pressure of digester.

Let the normal pressure of the digester is $P_i = 4\ kPa$.

and final pressure after gas being stored $= P_f$

The produced gas should have to stay within 35.8 cubic meters volume. So, according to boyle's law,

$$P_i \times (78.4 + 35.8) = P_f \times 35.8$$

$$Or, P_f = \frac{4 \times 114.2}{35.8} = 12.76\ kPa$$

Let, height of the hydraulic chamber is h. The pressure of the hydraulic chamber should be 12.76 kPa so that only the inlet recharge will be discharge.

$$P_f + H\rho g = H\rho g + h_1\rho g + h\rho g$$

$$Or, h + h_1 = \frac{P_f}{\rho g} = \frac{12.76 \times 1000}{1000 \times 9.81} = 1.3\ m$$

Let, height of the hydraulic chamber from digester manure level, $h_1 = 0.23\ m$

So, height of the hydraulic chamber, $H_H = 1.3 - 0.23 = 1.07m = h$

Now, the volume of the hydraulic chamber is equals to the discharge per day.

If D_H is the diameter of the hydraulic chamber then,

$$\pi \left(\frac{D_H}{2}\right)^2 h = 2.8$$

$$Or, D_H = \sqrt{\frac{4 \times 2.8}{\pi \times H_H}} = \sqrt{\frac{11.2}{3.1416 \times 1.07}} = 1.83\ m$$