Analysis of an Electrical Microgrid in a Remote Area Based on Distributed Energy Resources

A thesis submitted to the Department of Electrical and Electronic Engineering of Bangladesh University of Engineering and Technology in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

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APPROVAL

The thesis titled "Analysis of an Electrical Microgrid in a Remote Area Based on Distributed Energy Resources", submitted by Alimul Haque Khan, Roll No. 0409062126F, Session April, 2009 has been accepted as satisfactorily in partial fulfillment of the requirement for the degree of Master of Science in Electrical and Electronic Engineering on September 20, 2014.

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I, do hereby, declare that neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

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DEDICATION

This thesis is dedicated to my parents and my wife.

ABSTRACT

Generation of electricity in Bangladesh is mainly based on natural gas. However, the generation sector is experiencing shortfall of gas and thus the region under the supply zone is facing the problem of load shedding owing to lack of sufficient electricity supply from the generating stations. As a result, this sector is moving towards oil, which is a very costly solution. Besides these, there is a movement for coal-based generation to meet the energy demand. However, this one is more harmful for the environment. Importing energy from neighbouring countries is also an option for Bangladesh. In a conventional system, electricity has to be generated in a huge amount, and it is transported to the consumers through the long transmission lines and distribution systems. The losses and costs incorporated with these processes are not negligible. The cost increases especially when the service area is remote. In remote areas, local people use diesel generators for electrifying local markets and villages by means of local grids known as microgrids. However, these generators run for a few hours of the day and the generation cost is very high. The Solar Home System has been used to replace traditional kerosene-based lamps and enable the use of DC TV, DC fans and light bulbs from 1998 in Bangladesh. However, with the advancement of technology, the demand of the consumer is increasing significantly. To meet this growing demand, it is necessary to expand the national grid to cover those remote areas. Quality and reliable electricity supply to all could be possible by adequate generation of electricity as well as by setting up new transmission and distribution networks. However, this would require a huge amount of investment. Also, it will be associated with higher electrical loss and would require a longer time to be installed. As an alternative to this option, it may be possible to produce additional power at the consumer spots by using the locally available distributed energy resources, like solar PV, solar thermal, biogas, wind, hydro, micro-hydro and other available resources. Huge amount of power can be generated by incorporating multiple numbers of smaller generating units, which are distributed throughout the distribution network.

A new model to generate electricity with higher penetration rate of renewable energy usage has been explained in this work. To this end in view, an optimization algorithm has been developed to make proper use of the distributed energy resources and a novel method named “Consumer is Producer” has also been presented. The proposed model is capable of providing quality and reliable power with lower pollution, elimination of evacuation system, higher penetration rate of renewable energy with easier installation and maintenance. Besides these, this model could be used to unlock the potential of engaging a large number of population into the power market and thus producing huge amount of electricity within the minimum possible time. The mathematical modelling has been carried out using MATLAB programming environment. An online database named “PVwatt” is also used to collect and use the relevant data and information in the analysis. Finally, the performance of the proposed model has been compared with that of the traditional power system.

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ABBREVIATIONS

AAAC	All Aluminium Alloy Conductors
AC	Air Conditioner Or Alternating Current
ACSR	Aluminium-Conductor Steel-Reinforced
ADB	Asian Development Bank
APSCL	Ashuganj Power Station Company Ltd.
BADC	Bangladesh Agriculture Development Corporation
BERC	Bangladesh Energy Regulatory Commission
BDT	Bangladeshi Taka
BPDB	Bangladesh Power Development Board
BTS	Base Transceiver Station
BWDB	Water Development Board
CC	Correlation Co-Efficient
CG	Centralized Generation
CPU	Consumer Producer Unit
DC	Direct Current
DESCO	Dhaka Electric Supply Company
DER	Distributed Energy Resource
DFID	Department For International Development (Dfid)
DPDC	Dhaka Power Distribution Company
EGCB	Electricity Generation Company Of Bangladesh
FO	Furnace Oil
FY	2013 Fiscal Year
GPOBA	Global Partnership Of Output-Based Aid

ABBREVIATIONS

GOB	Government Of Bangladesh
GTS	Gas Turbines
GWH	Giga Watt Hour
HFO	Heavy Fuel Oil
HSD	High Speed Diesel
HVDC	High Voltage Direct Current
IDCOL	Infrastructure Development Company Ltd
IPP	Independent Power Producers
KfW	Kreditanstalt Für Wiederaufbau (German Development Bank)
KV	Kilo Volt
KWH	Kilo Watt Hour
MVA	Mega Volt Ampere
MW	Mega Watt
MPEMR	Power Division, Ministry Of Power, Energy & Mineral Resources
NGOS	Non-Governmental Organizations
NREL	National Renewable Energy Lab
NWPGCL	North West Power Generation Company Ltd.
PBS	Palli Bidyut Samiti
PGCB	Power Grid Company Bangladesh
PGEL	Purobi Green Energy Limited
PO	Partner Organizations
PSMP	Power System Master Plan
PV	Photovoltaic

ABBREVIATIONS

REB	Rural Electrification Board
SHS	Solar Home System
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organisation)
STS	Steam Turbines
T&D	Transmission And Distribution
USAID	United States Agency For International Development
WZPDCL	West Zone Power Distribution Company Limited
XLPE	Cross-Linked Poly Ethylene

CHAPTER 1

INTRODUCTION

Bangladesh is a developing country with huge population. Development of a country mostly depends on ensuring reliable and quality power to everywhere in the country. Due to unavailability of transmission and distribution network infrastructure, about 45% [1] of the population of Bangladesh remains off grid. Moreover, the grid areas are facing acute load shedding for lack of adequate generation. Per capita electricity generation of Bangladesh is 321KWh [2]. Bangladesh Government has set up its goal to ensure reliable and quality supply of electricity at a reasonable and affordable price to all by 2021 [1]. For sustainable social and economic development, it needs adequate power generation capacity.

People in the off grid areas of Bangladesh are mainly using fuel-based lamps as the lighting sources. Some of them are using electricity by means of local grid based on diesel/petrol generators that run for a few hours in a day. Some people use storage battery to be charged from the local grid or from the nearest national grid and use it for powering direct current (DC) light bulbs, small fans and black and white televisions for weeks. Besides these, the Solar Home System (SHS) of Infrastructure Development Company Ltd (IDCOL) offers the best way to the battery charging based electricity practice [3].

People had a nice feeling when they experienced the benefit of using a switch-based higher luminous bulb through SHS instead of oil-based lower luminous lamp. However, with the advancement of modern technology and globalization, the energy demand of existing users of SHSs is also increasing day by day. They are now willing to use ceiling fans, Television (TV), computer, blender, fridge, domestic water pump, air conditioner (AC) and other domestic appliances as well.

The Renewable Energy Policy of the government of Bangladesh envisions that 5% of the total energy production will have to be achieved by 2015 and 10% by 2020 [4], [5]. Power generation by fuel diversification is the best way to accelerate the development of renewable energy. There is no doubt that a higher penetration of renewable energy in the overall energy consumption will reduce the greenhouse effect drastically.

1.1 Literature Review

The electricity generation of the country is dependent mostly on the natural gas; a small part of the generation comes from hydro, oil and coal. Under the existing generation scenario of Bangladesh, a major portion of the generated electricity comes from natural gas, which is about 80% [1] of the total generation and is not enough to serve the demand. Other sources of energy are oil and coal. Due to shortfall of natural gas, generation units often fail to reach its rated capacity. On the other hand, oil is being subsidized. Moreover, the prime concern about this type of fuel is the emission of carbon-di-oxide (CO_2) which accelerates the greenhouse effect and thus the global warming. The only renewable energy source of the country that is connected to the grid, is the Kaptai Hydro power plant, which has a very small share (around 2. 58%) [1] of the total generation. Apart from this, some small and remote areas are being served by diesel generators by means of a local grid, which is defined as a microgrid [6]-[8]. Demand can also be met by connecting several microgrids locally, where installation of additional transmission lines, as in the conventional power stations, is not necessary as the sources are closer to the consumer and discretely located at different places of the microgrid. The discretely situated distributed energy resources (DERs) are being used as a supplement and an alternative to large conventional central power systems worldwide [9]-[11] and the penetration of DERs at medium and low voltage levels is increasing [12]-[14]. In those countries, the size of the DERs is large and most of them are interconnected to the national grid. The size of the energy resources used in local microgrid in Bangladesh is small and the scale of the microgrids is also small because of less electricity demand. The energy resources used in the isolated microgrids that are setup by the local people to meet their own needs are centralized. The available renewable energy sources in Bangladesh may be used as DER in a microgrid, which may meet a significant proportion of the national demand of electricity with a competitive price compared to the traditional power plants. Analysis of various factors by using large-sized DERs has been carried out in those countries. However, for the proposed small scale microgrid in Bangladesh, the size of the DERs will be small and decentralized. The analysis of the relevant factors of such scheme has not yet been carried out. We proposed to make the use of the available small scale energy resources in a decentralized manner in our small scale microgrid.

1.2 Scope of the Current Work

The available renewable energy resources in Bangladesh are hydro, solar, wind, biomass, tidal and wave, and geothermal. Among them hydroelectric power shares the maximum generation capacity of 230MW. Potential of Solar photovoltaic (PV) is available all over the country. Solar PV programs have also gained a large number of installations [3]. There are some suitable locations for installing wind farms of which few are in operation, some are in maintenance and many of them are in feasibility study. The biogas sector is also enriching, but most of the biogas plants are not used to generate electricity, rather they are used for cooking. The potentials of tidal, wave and micro hydro are promising but those are also at the level of feasibility study. The potential of extracting geothermal energy is little for Bangladesh. Using the solar PV resources and other available resources, it is possible to generate electricity that would be adequate to meet the local demand. This principle could be used all over the country. This is how a significant percentage of population may be brought under the electricity coverage region.

1.3 Objectives

The objectives of this research are:

- (a) To study the available resources of the renewable energy at various places of Bangladesh.
- (b) To study the evacuation system of the national grid and the present microgrid located at different places in the country.
- (c) To study the national load profile and microgrid load profile.
- (d) To search for an alternative and supplement to further extension of the present power system.
- (e) To design a mathematical model for the proposed alternative.
- (f) To compare the performance of the proposed alternative with that of the traditional system.

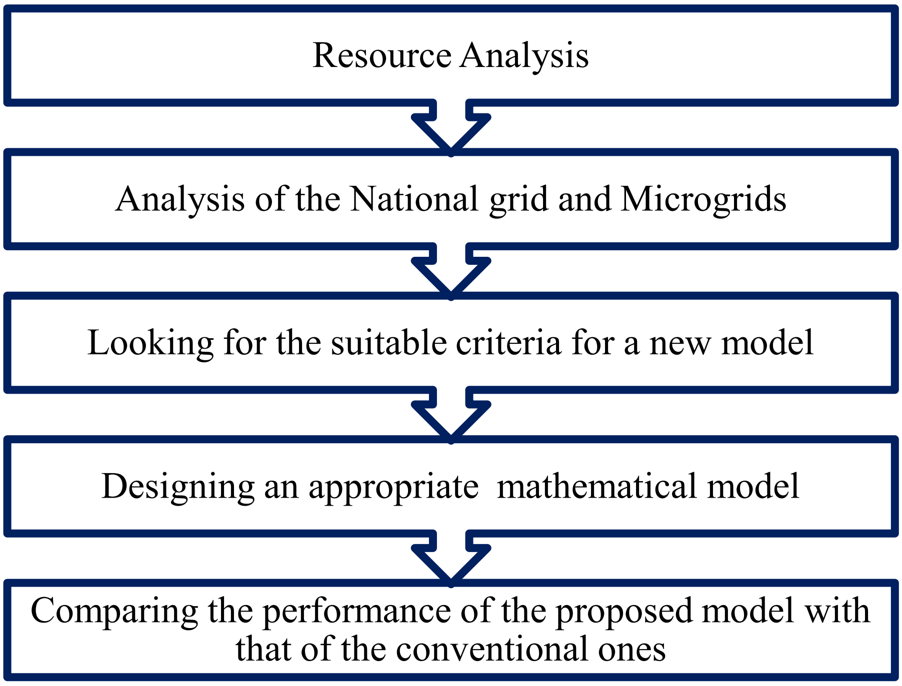
1.4 Features of the Alternative to the Present Power System

The alternative to the present power system is expected to have the following features:

- (a) Be suitable for the remote area considering the area, density of population, load profile, availabilities of alternative power resources.
- (b) Be economically feasible and cost effective.
- (c) Create market for the common people. As a result, acceleration into the power business should be possible.
- (d) Minimize the cost and loss associated with the evacuation.
- (e) Eliminate the transmission network as well as primary distribution network, by low-level secondary distribution networks.
- (f) Decrease the Carbon emission as well as lower greenhouse gas emission and decelerate the higher rate of global warming.
- (g) Have a reliable load management system as well as source management system.
- (h) Be reliable for the extreme critical condition of the power system.
- (i) Be easy to install and easy to maintain. The plug and play type easier installation could ensure the minimum installation time.
- (j) Minimum installation and running cost.

1.6 Methodology

The methodology of the research work may be shown by the following flow chart.



1.7 Layout of the Dissertation

Chapter 1 introduces the present scenario of electricity demand and generation of Bangladesh and emphasizes the necessity of an alternative and supplement to the existing power system.

Chapter 2 describes the available topologies for electricity generation and its evacuation system in Bangladesh.

Chapter 3 discusses the centralized generation system and the distributed generation system as well as the national grid and the local microgrids.

Chapter 4 describes the available renewable energy resources and its potential for Bangladesh.

Chapter 5 introduces a novel model that has been proposed for an electrical microgrid in a remote area based on the available distributed energy resources.

Chapter 6 explores a new model to generate electricity with higher penetration rate of renewable energy.

Chapter 7 shows some of the results obtained from the proposed model with the help of the developed software routines.

Chapter 8 summarizes the findings and achievements of the current research. It also suggests some possible extensions to substantiate the current research in future.

CHAPTER 2

A REVIEW ON ELECTRICITY GENERATION AND EVACUATION SYSTEM IN BANGLADESH

This chapter describes the available topologies for electricity generation and its evacuation system in Bangladesh. Usually, electricity is generated in a large power station and it is then sent to the customer end by means of transmission and distribution systems. This is an established technology. However, this system proves very costly and the cost increases especially when the service area is remote. In remote areas, local people use kerosene as a fuel for lighting. Also, diesel generators for electrifying local markets and villages are being used. However, these generators run for a few hours of the day and the generation cost becomes very high. Practice of battery charging based electricity system is also found in many places of the remote area. Besides these, Government of Bangladesh (GOB) is trying to electrify the remote areas by means of SHS, which has been being used to replace the traditional kerosene-based lamps from 1998 in Bangladesh. However, with the advancement of technology, the new demand for SHSs and more energy demand of existing SHS consumers is also increasing considerably. Electricity to all is an essential requirement for the proper development of Bangladesh. Thus, it is essential to supply power with quality and reliability to the present users of the national grid, customers of the SHS and people of the un-electrified region. With this context, possibilities of exploring new topologies of generation and evacuation have also been discussed in this chapter.

2.1 Electricity Generation and the Grid

Producing electrical power by means of any energy conversion method is known as electricity generation. Large scale electricity is basically produced from rotary machines such as gas turbine, steam turbine, hydro-turbine and engines etc. The necessary systems that are needed to transfer power from the generating unit to the customer end are known as the evacuation system.

Bangladesh is a small country with large amount of population. Presently, 55% [1] of the total population has access to electricity and per capita generation is 321KWh [2]., which is very low compared to other developing countries. There are mainly three major methods or topologies of supplying electricity to the customers in Bangladesh.

The first one is the traditional large-scale centralized generation, where electricity is generated from hydroelectric power plants, gas turbines, steam turbines, gas engines and diesel engines and by many other means. In a hydroelectric power plant, potential energy of the reserved water is converted into electrical energy. The cost involvement is only for installation, operation and maintenance. On the other hand, steam Turbines (STs), Gas Turbines (GTs) or engine generators are based on fuel such as natural gas, High Speed Diesel (HSD), Furnace Oil (FO), Coal etc. The concerned authority of the Government of Bangladesh, Bangladesh Power Development Board (BPDB) is generating power by its own generators as well as purchasing electricity from other private companies [1]. Whoever produces the electricity is then transmitted and distributed to the consumer end by means of the available transmission and distribution (T&D) system. The T&D system needs special infrastructure, which is very costly [2].

The second one may be termed as the single unit generation i.e. a standalone system that does not need any T&D system such as the solar home system (SHS), solar irrigation system etc. Along with the centralized generation, till now (October, 2014) more than 3 million (3,258,653) SHSs have already been installed in the off-grid rural areas of Bangladesh under the program run by IDCOL with the co-operation of several Non-Governmental Organizations (NGOs). As a result, more than 13 million beneficiaries are getting solar electricity, which is around 9% of the total population of Bangladesh. Most of the installed SHS units are used at home, few of them are used in educational institutions, prayer houses and shops in the market. A SHS is able to provide electricity for a few light bulbs, small DC fan and TV, rechargeable torchlights and adapters for mobile phone charging [3].

The third method of supplying electricity is the local grids run by small-scale diesel/petrol engines at the remote areas. These topologies are shown in the following flow chart in Figure 2.1. Local grid is shown between the extreme two cases.

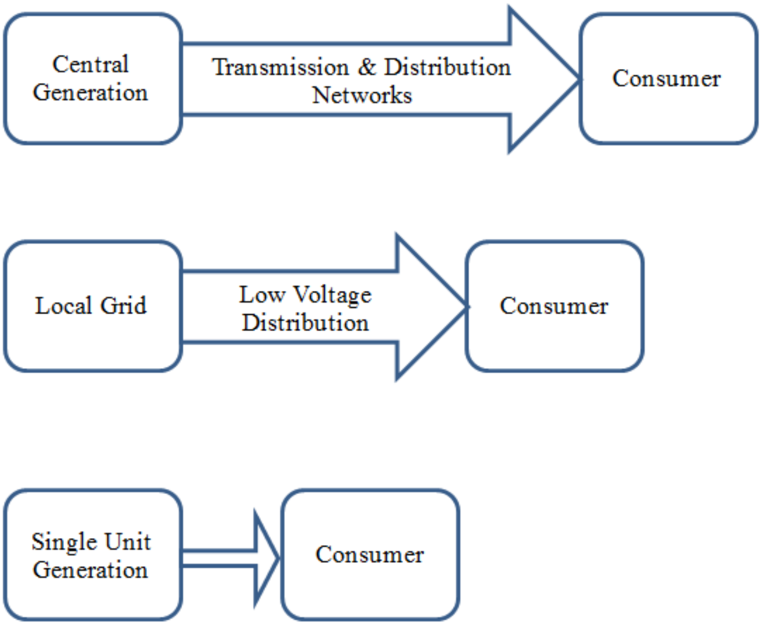


Figure 2.1: Three topologies of generation and evacuation of electricity in Bangladesh.

Unfortunately, the third method of supplying electricity has not been taken into consideration by the policy makers and has so far remained neglected. These generation units are distributed all over the remote areas of the country and are not interconnected in any way. The generated energy is locally consumed with a low voltage distribution line. However, generation cost is also high in this case. These are operated by local electricians/operators in most of the cases and thus it has enough risks of electrical hazards.

2.2 Generation

Most of the power stations in Bangladesh are based on natural gas, which is around 80% of the total capacity on the fiscal year (FY) 2013 [1]. On the other hand, gas is short supply and about 1500 MW of generation shortfall occurs in a day due to shortage of gas [15]. Therefore, it will be very tough to provide more electricity generated from the natural gas in future. The daily reports of Power Grid Company Bangladesh (PGCB) show the decreasing supply of natural gas and more and more penetration of oil-based generation. Government of Bangladesh is trying some alternative to natural gas such as coal, HSD and Furnace oil based power plants under the fuel diversification program [1]. So far, as the fuel is concerned, the generation capacity is 6,719 MW by Natural Gas, 1,963 MW by heavy fuel oil (HFO), 783 MW by high speed diesel (HSD), 230 MW by Hydro and 200 MW by Coal. Besides these, 500MW has been imported from India since November, 2013 via high voltage direct current (HVDC) transmission line. Table 2.1 shows the installed capacity of Power Plants in Bangladesh according to fuel [16].

Table 2.1 Installed capacities of power plants in Bangladesh according to fuel.

Unit Type	Capacity(Unit)	Total (%)
Coal	250.00 MW	2.39 %
Gas	6719.00 MW	64.33 %
HFO	1963.00 MW	18.79 %
HSD	783.00 MW	7.5 %
Hydro	230.00 MW	2.2 %
Imported	500.00 MW	4.79 %
Total	10445.00 MW	100 %

Presently, the use of natural gas, HSD, Coal and HFO are around 80%, 10%, 5%, and 3% [15], respectively of the total generation. Bulk of the power in Bangladesh is generated by BPDB. There are other independent power sources as well.

Power Division, Ministry of Power, Energy & Mineral Resources (MPEMR), and Bangladesh Energy Regulatory Commission (BERC) are the governing bodies of Power Sector of Bangladesh.

The following authorities are responsible for generating electricity in Bangladesh.

(i) Bangladesh Power Development Board (BPDB)
(ii) Ashuganj Power Station Company Ltd. (APSCL)
(iii) Electricity Generation Company of Bangladesh (EGCB)
(iv) North West Power Generation Company Ltd. (NWPGCL)
(v) Independent Power Producers (IPPs)

Table 2.2 shows the de-rated generation capacity and their market share for the five authorities of electricity generation [16].

Table 2.2: Various authorities, de-rated capacity and their market share.

SL No	Name of the Authorities	Capacity	Market Share
01	Bangladesh Power Development Board (BPDB)	4442	42.75%
02	Ashuganj Power Station Company Ltd. (APSCL)	682.	6.56%
03	Electricity Generation Company of Bangladesh (EGCB)	622	5.98%
04	North West Power Generation Company Ltd. (NWPGCL)	375	3.06%
05	Independent Power Producers (IPPs)	4269	41.08%
Total		10390	100%

All the generated power are purchased by the BPDB and then transmitted by PGCB to the customers‟ premises. The generation cost and purchase cost of each unit (KWh) of electricity is shown in the table 2.3 below [1]. The Snapshots of these costs are given at Appendix-A.

Table 2.3: Cost of generation and purchase for various types of fuel.

Purchase cost		
Type	**Maximum Cost / Tk. per unit**	**Average Cost / Tk. per unit**
Rental Gas	5.97	4.58
Rental HFO	25.70	17.58
Rental Diesel	35.03	27.24
Rental Average		10.99
Generation Cost		
Hydro	0.88	0.88
Gas	5.87	1.97
Coal	5.71	5.71
HFO	50.60	17.85
Diesel	53.63	43.91
Total Average of Generation and Purchase		**3.80**

Till September, 2014 the total generation capacity of Bangladesh is 10,445 MW the de-rated capacity is 10,390 [16]. It should be noted here that 3.11% and 11.95% of generated energy are lost due to transmission and distribution, respectively [1].

The major part of the generation comes from the natural gas, for which the cost of generation of per unit energy is lower. However, it is higher for HSD and HFO due to high price. Energy Flow Chart of FY 2013 [1] shows that 77.91GWh of energy is produced from 34.79 Million liters of Diesel costing diesel of about 30.364 Bangladeshi taka (BDT) per kWh of energy whereas it is 13.46BDT for Furnace oil, 3.7BDT for coal and 0.902BDT for gas-based generation on an average (only for BPDB Generation). However, these costs are only for fuel. The actual cost is much higher when other running and maintenance costs are included. It should be noted here that the overall thermal efficiency of the power plants is 33% and the annual plant factor is 45.02%. Table 2.4 shows the percentage of the generation and its corresponding costs for various types of fuel for BPDB only [1]. These data are only for the generation of BPDB and other generations are not included here. This could be found at Appendix-A.

Table 2.4: Percentage of the generation and its corresponding fuel costs.

Fuel Type	% of Total Generation	% of Total Fuel Cost
Diesel Oil	1.805979438%	28.3247319%
Furnace Oil	2.136239115%	24.4400091%
Coal	5.894480959%	10.9173104%
Natural Gas	85.08369443%	36.3179485%
Water	5.079606058%	-

Based upon the preliminary study of the Power System Master Plan (PSMP) -2010, the anticipated peak demand would be about 10,283 MW in FY2015, 17,304 MW in FY2020 and 25,199 MW in 2025. The policy envisions 800MW of power from renewable energy by 2015 and 200MW of power by 2020[17]. According to PSMP-2010 Study year-wise peak demand forecast is shown in Table 2.5.

Table 2.5: Year wise peak demand forecast.

Fiscal Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Peak Demand (MW)	6,454	6,765	7,518	8,349	9,268	10,283	11,405	12,644	14,014	15,527	17,304	18,838	20,443	21,993	23,581	25,199	26,838	28,487	30,134	31,873	33,708

2.3 Transmission and Distribution

The only company that works for the transmission of electricity in Bangladesh is the Power Grid Company of Bangladesh Ltd. (PGCB).

As of June 2013, there is almost 3,020 km of 230 kV and 6,148 km of 132 kV transmission line available in the country. The number of 230/132 kV substations is 16 and combined capacity of those entire substations is 7,525 MVA. Besides, there are 103 substations of 132/33 kV available throughout the country with a capacity of 11,792 MVA. The distribution network is the biggest of the lot, with 3,728 km, 13,128 km and 21,839 km of 33 kV, 11 kV and 400 V lines, respectively. There are 158 substations of 33/11 kV for distribution of power around the country [2].

Four companies are distributing the generated power along with BPDB. BPDB is responsible for distribution of electricity in most of the urban areas in Bangladesh except Dhaka Metropolitan City and its adjoining areas under Dhaka Power Distribution Company Limited (DPDC) and **Dhaka Electric Supply Company Ltd. (DESCO),** areas under West Zone Power Distribution Company Limited (WZPDCL) and some of the rural areas under Rural Electrification Board (REB). The Distribution Zones of BPDB are Chittagong, Comilla, Sylhet, Mymenshing, Rajshahi, Rangpur. 40.10% of the said generated power is purchased by REB and distributed to the pastoral area. BPDB distributes 24.64% of the power among the urban consumers. DPDC and DESCO distribute 18.59% and 10.51% respectively, of the power among the consumers in Dhaka metropolitan area. The rest 6.17% of the power is distributed by WZPDC in Khulna and Barisal divisions [1]. 46.52% of the power is used for resident loads, 10.34% for commercial purposes, 37.42% for industries, 3.17% for agriculture and 2.56% for other purposes [1]. The share of electricity distribution by the relevant authorities has been shown in Table 2.6.

Table 2.6: The share of electricity distribution by the relevant authorities

Authority	**BPDB**	**DPDC**	**DESCO**	**REB**	**WZPDC**
Share in Percentage	24.64%	18.59%	10.51%	40.10%	6.17%

Among the distribution authority, REB has the highest share of electricity distribution. REB is working through Palli Bidyut Samiti (PBS) working over the country. The customer density of PBS is around 35. The urban areas are denser than rural areas. The customer densities of several PBSs are shown in Figure 2.2.

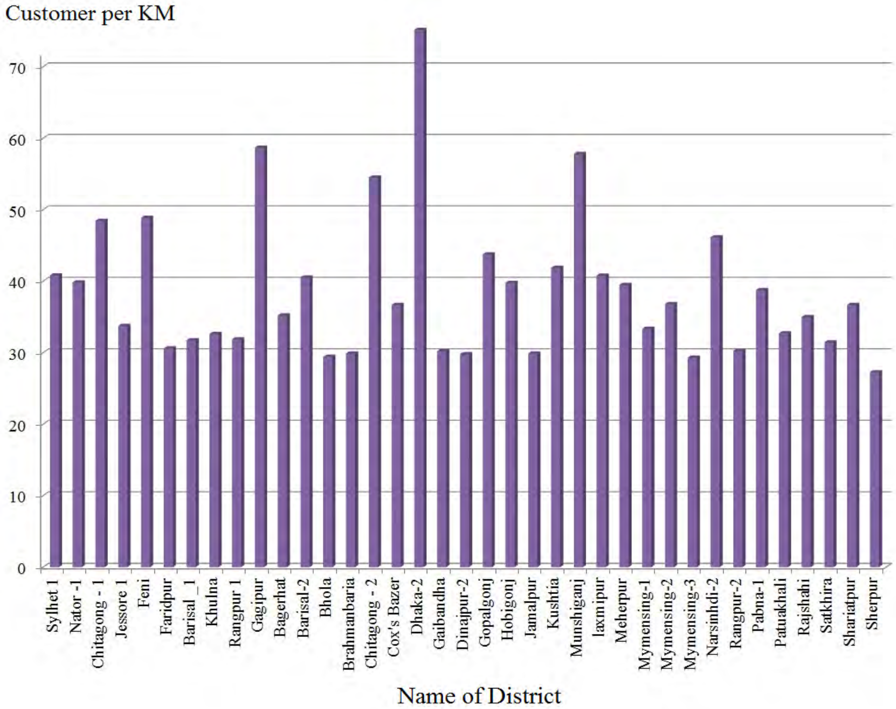


Figure 2.2: Customer density of PBS for several districts.

The summary of the length of transmission and distribution lines at various levels is given below:

(a) 230KV:1324.40 km route and 3020 ckt km
Used conductor: Mallard, twin mallard, Twin AAAC, finch, ACSR

(b) 132KV: 3505km, 6148 ckt km
Used conductor: Grosbeak, AAAC, HAWK, Cu.Cable, XLPE, Twin AAAC

(c) 33KV feeder length:3728km

(d) 11KV feeder length: 13128km

(e) 0.4KV feeder length: 21839km

2.4 Local Mini Grids

There are a number of local grids in the remote areas of Bangladesh. Most of the local grids in Bangladesh are run by diesel generators. Remote villages and markets have local grids. However, the electricity is available only for a few hours, and used mainly for lighting purposes only. Most of the grids have a generation scale of 5kW ~ 10kW diesel generators serving about 20~50 number of customers/shops.

These grids may be defined as mini grid or micro grid. In a microgrid, no transmission line is needed, only low voltage distribution lines are necessary. Here, bamboo poles or other supporting elements are used instead of the standard poles. The generation cost is around 30Tk per kWh. However, a customer is charged around 50Tk. per kWh.

Besides these, solar PV based mini-grid projects are installed in remote areas of the country, where possibility of grid expansion is remote in the near future. These projects provide grid quality electricity to households and small commercial users, and thereby encourage commercial activities in the project areas.

So far, IDCOL has financed one 100 kWp solar microgrid project in Sandwip Island. The project is currently supplying electricity to adjacent 250 shops, 5 health centers and 5 schools. Another four projects of different capacity (100~159 kWp) have been approved by IDCOL which are in various stages of construction. IDCOL has a target to finance 50 such solar mini-grid projects by 2017.

2.5 Complete Stand-Alone System

A complete stand-alone system has no distribution system. The generated electricity is sent to the load directly or via a storage device. Such an application is solar home system (SHS).

At present 47 Partner Organizations (PO) are implementing the program under the supervision of IDCOL. More than 3 million SHSs have already been installed under the program in the off-grid rural areas of Bangladesh. As a result, 13 million beneficiaries are getting solar electricity, which is around 10% of the total population of Bangladesh. More than 65,000 SHSs are now being installed every month under the program. IDCOL has a target to finance 6 million SHSs by 2017, with an estimated generation capacity of 220 MW of electricity.

Solar Photo Voltaic (PV) is used to convert the energy of sunlight into electrical energy. The unit is named as solar cell, it is a junction made from the p-type and n-type semiconductor (silicon). Incident light ray with certain wavelength will make emission of electron from the junction producing flow of electron or electric current. Several cells will form a solar panel/module and several panels/modules will form a solar array.

The electricity generated from the sunlight by the solar PV panel could be utilized in several ways. Due to some limitation, this energy cannot always be used directly to the load. At night the production is zero and at foggy, cloudy or rainy day the output is very low. This is called intermittent source [18]. Due to the intermittency, output of the panel is not constant; it just fluctuates. This fluctuation may hamper the load and may even damage it. Hence, most of the application needs battery as a backup to solve the problem of intermittency except the solar irrigation system, solar PV based battery charging station, grid tie system etc. For a larger system other resources may be used. SHS is remarkable among the application of solar PV. Conventional SHS have light bulbs as load that runs at night. In some cases, low power DC fan and TV are also used. The only way to use this electricity at night is to store the energy in a battery. Therefore, in this system battery is mandatory. Storing the electricity produced by the panel into the battery is known as charging and using the storage energy from the battery by the load is known as discharging. The length of duration while the battery can store and deliver the energy to the load properly is defined as the life time of the battery. It is specified by the number of cycle it is charged and discharged as well as years of operation. If the charging and the discharging are not taken place properly, the life time of the battery will be decreased. Too much charging or discharging is bad for the battery. To ensure this operation properly a charge controller is used. It may be compared to the brain of the total system**.** It will protect the battery, panel and the load from current reversal, overcharging, deep discharging, short-circuit and other bad impacts. The complete process is shown in the block diagram of Figure 2.3.

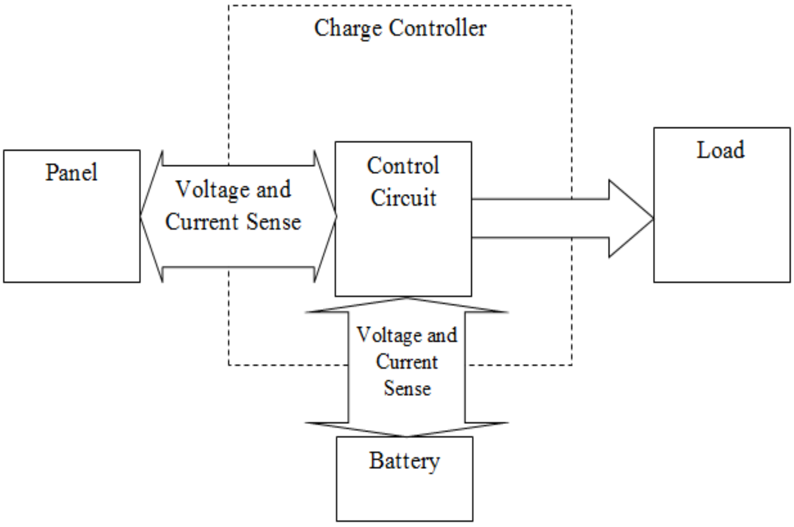


Figure 2.3: Block diagram of a SHS showing the Panel, Battery, Charge Controller and Load.

2.6 Possibilities of Using Electrical Microgrids in Bangladesh

As discussed earlier, a conventional power system consists of large-scale power stations, transmission lines, substations and distribution lines etc., where the generation and consumption of power are not at the same location. Due to unavailability of enough T&D lines, remote areas are normally not connected with the electrical grid, thus these areas are deprived of development. On the other hand, SHS is being used drastically at the remote areas. Although the number of installed SHS unit is high enough, the total amount of electricity produced by these is not significant yet. Moreover, this is not a permanent solution of electricity. In this context, a local grid may offer a better alternative. Government has planned to install several microgrids at some selected region to add more power in the national generation from the renewable energy sector. Also, the Government has a plan to replace 19,000 number of diesel pumps with the solar PV system as well as installing some mini-grids at various remote sites [19].

Owing to some important factors as will be discussed next, it is a high time to think of the higher penetration of renewable energy into the generation of electricity in a decentralized manner as proposed. For the traditional power generation systems, fuel cost for oil-based plants is high and sometimes it exceeds 30Tk per KWh [1]. The generation cost of natural gas based electricity is lower but, the reserve of our natural gas is going to be diminished very soon. Shortfall of generation due to shortage of enough supply of natural gas is common for generation [15]. Besides these, most of the generation units emit high amount of CO_2 which increases the greenhouse effect and the global warming. In addition, the cost and loss associated with the evacuation system is not negligible either. Moreover, interruption at any node in the grid turns into load shading and hampers a lot of users, when many customers get completely disconnected from the grid.

If the generation units (diesel generator) of local grids could be replaced by the solar PV as well as creating new small grid based on solar PV, and these grids could be interconnected to some extent, the problem of electrifying the remote areas may be solved in a greater degree[27]. For example, a 10MW capacity power station may be replaced by installing 1000 number of generating units with 10KW capacity each, which are situated at different locations through an interconnected gird. It would not require any transmission network; rather a low voltage distribution network may be used for the distributed generation.

Similarly, if the outputs of each PV panels are interconnected locally, then it would be able to provide the required energy sufficient for all the users of the locality by means of a Microgrid [7]-[8]. A microgrid is a group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can be connected and disconnected from the grid to enable it to operate both in grid-connected or in island-mode [20]. The available renewable energy sources in Bangladesh may be used as DERs in a microgrid, which will reduce the control burden on the grid and may meet a significant proportion of the national demand of electricity with a competitive price compared to the traditional power plants. The penetration of DER based microgrid is increasing in the developing country day by day. Moreover, a microgrid can be interconnected to any adjacent microgrid in case of emergency. Interconnected microgrids have more opportunities to share generated power among various loads and make it easier for load management and control. With proper design and implementation, interconnected microgrids have ample scope to be connected with the national grid without the need of installing new transmission lines [14].

I.

2.7 Summary

Considering the possibilities of incorporating electrical microgrids, new models for generation and distribution of electricity should be in the agenda of power planning cell of the Government of Bangladesh. It is expected that by incorporating electrical microgrid, transmission and distribution loss and overall cost of electricity production will be minimized significantly. Also, the emission of CO_2 will be negligible with a new load management technique, and reliable and high quality power may be ensured within the shortest possible time. The proposed model could be used as an alternative to the bulk scale generation and supplement the traditional power system. Installation of large power plant based on renewable energy resources is good. However, the scope of implementation is not available everywhere in Bangladesh. Moreover, it also needs the evacuation system, which is still costly even though loss has been minimized. On the other hand, the installed number of SHSs in the country is huge (more than 3 million) but its share to the total generation is not that significant. Moreover, it is not contributing to the national grid in any way. Therefore, proper sizing of the power sources are important as well as designing the appropriate evacuation system. Keeping this context in mind, distributed energy resources and the microgrid are discussed in the next chapter.

CHAPTER 3

DISTRIBUTED ENERGY RESOURCES AND THE MICROGRID

The last chapter reviewed the electricity generation and evacuation system in Bangladesh. This chapter discusses the centralized generation system, distributed generation system, the national grid and the microgrid. A credible alternative generation paradigm, distributed generation has been discussed to overcome significant technical, economic, regulatory and environmental hurdles. Electricity is mainly produced at large generation facilities, shipped through the transmission and distribution grids to the end consumers. However, the recent quest for energy efficiency and reliability and reduction of greenhouse gas emissions led to explore the possibilities to alter the current generation paradigm and increase its overall performance. In this context, one of the best alternatives, complements or even replacing paradigm is the distributed generation, where electricity is produced next to its point of use. Distributed Energy Resources (DERs) can provide solutions to overcome the shortfalls of the centralized generation. Environmental concerns also led regulators to promote efficient generation technologies.

3.1 Distributed Energy Resources

In Bangladesh, most of the power is generated from large-scale traditional centralized power stations. The generated power reach to the consumer through transmission and distribution (T&D) network associating higher loss and cost. The remote areas increase the cost and loss much more. However, large-scale power can be generated by multiple smaller scale power generation units, which are located at several locations within the entire service area. This is also known as decentralized generation or distributed generation, generating power in a decentralized manner [7].

For example, 500MW of power may be generated in a single power station or it may be generated by installing 500 numbers of generating units of 1MW, which are situated at different locations throughout the gird. Decentralization of generation removes the transmission network and only a low voltage distribution network is associated with it.

Distributed energy resources are small, modular, energy generation and storage technologies that provide electric capacity or energy where it is needed. There are options to be either connected to the local electric power grid or isolated from the grid in stand-alone applications for DER based system. DER technologies include wind turbines, photovoltaic (PV), fuel cells, micro-turbines, reciprocating engines, combustion turbines, cogeneration, and energy storage systems [21].

Distributed energy generation is a local and decentralized energy production system. A decentralized energy system is characterized by locating of energy production facilities closer to the site of energy consumption. As a relatively new field of research, several expressions are still currently used such as “decentralized generation”, “dispersed generation”, or “distributed energy resources” etc [22].

Distributed generation may be defines as a generator with small capacity close to its load that is not part of a centralized generation system. Also it is such kind electric power source that is connected directly to the distribution network or on the customer site of the meter. The key criteria in the definition of DER are the connection to the distribution network and the proximity to the end consumer.

The complete discussion on the distributed generation system may be exemplified with the following example and Figure 3.1 to Figure 3.6.

Figure 3.1 shows that a large, remote, centralized and conventional power plant, which may be run by natural gas, oil, coal, nuclear or massive wind or hydro power plants connected to the power system. It needs transmission and distribution lines for energy consumption at the consumer end which is shown in Figure 3.4 and Figure 3.5.

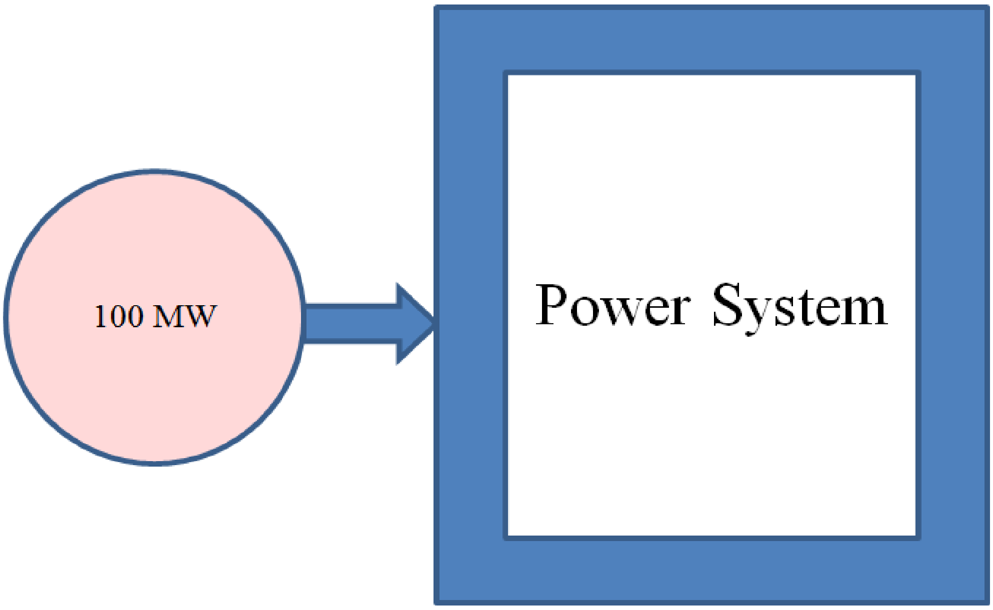


Figure 3.1: Traditional power system.

On the other hand, the same amount of power may be generated from multiple numbers of smaller generating units, which is shown in Figure 3.2; this is an idea of distributed energy resources. However, the size and scale is an important factor. The size is yet too large (10MW) and is associated with transmission system.

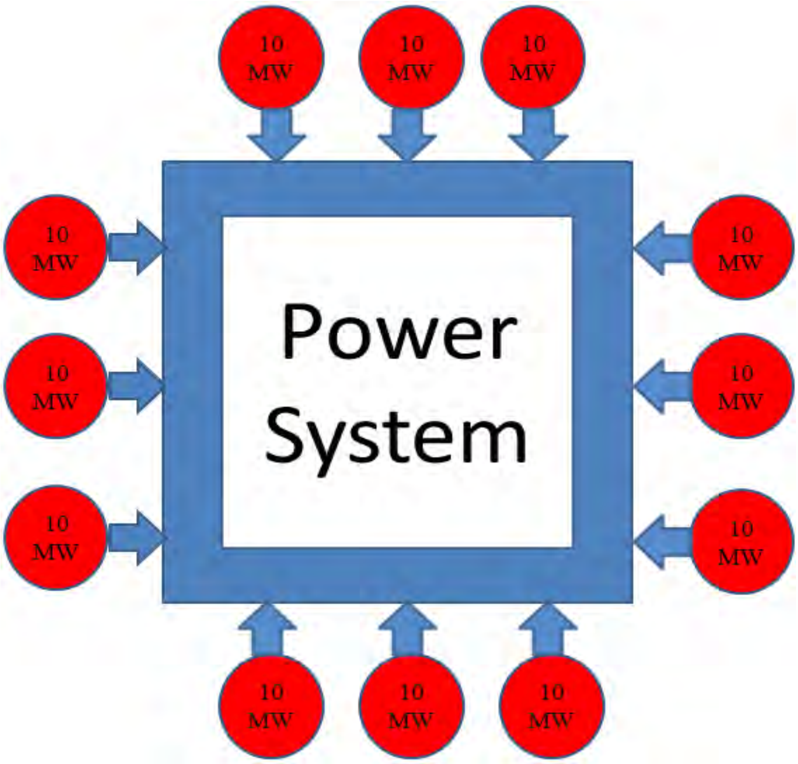


Figure 3.2: Distributed Energy Resources (larger size needs both T&D).

Same idea could be applicable for a smaller distributed generation. Figure 3.3 shows smaller size of distributed energy resources, which needs no transmission system at all.

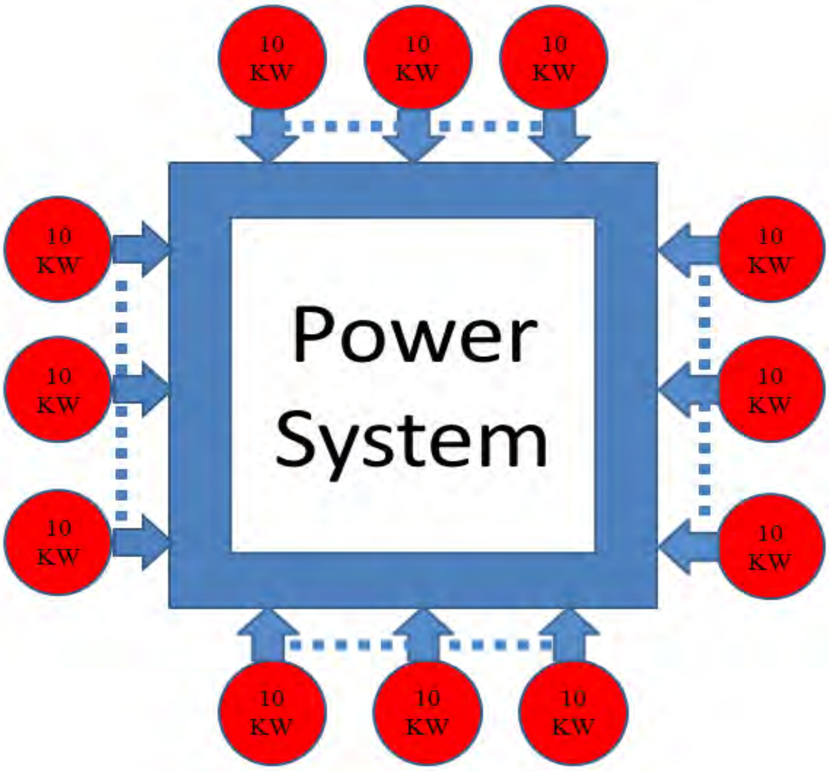


Figure 3.3: A DER (smaller size) based power system need no transmission line.

Figure 3.4 expresses same idea with a flow chart of power flow.

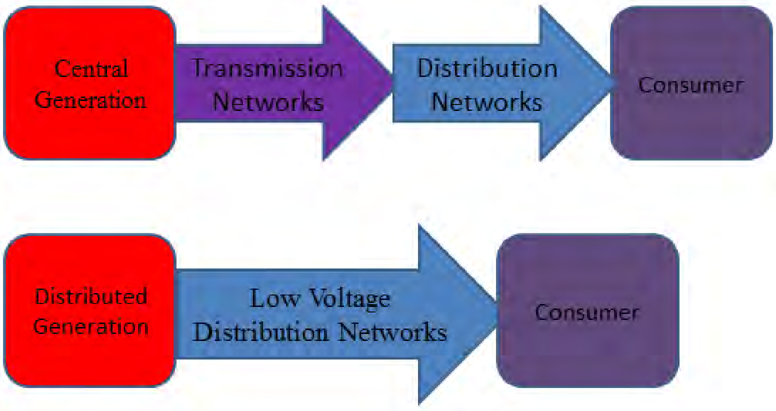


Figure 3.4: Flow chart of power flow in central generation and distributed generation.

Figure 3.5 shows the idea of the traditional centralized power generation by a ring diagram, in a different way. Here, generation, transmission, distribution and consumer network all are shown by rings with different color and radius. The flow of power is also shown by the arrow.

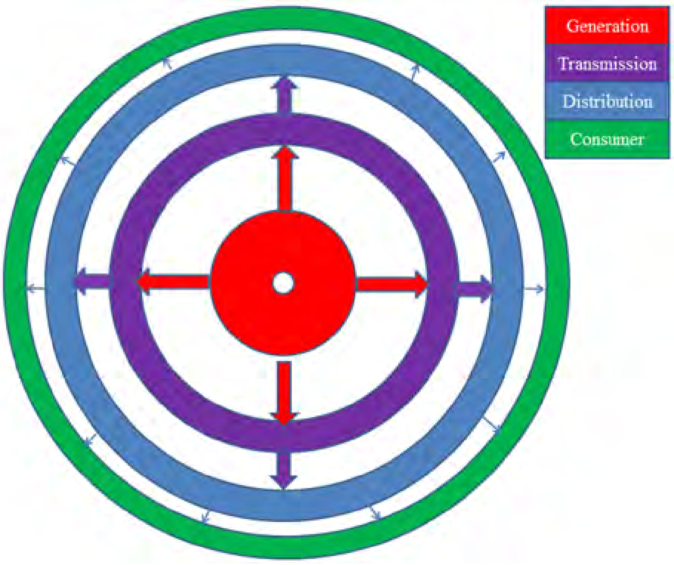


Figure 3.5: The traditional power system with a central generation.

The red ring/circle at the center denotes the central generation. The outer ring over the generation ring signifies the transmission layer. This ring has a color of purple. The ring after transmission layer which is blue in color is indicating the distribution layer. Thus, the outermost ring is indicating the consumption layer. The generations are not concentrated in a place rather and the units are distributed over the entire grid. However, this type of grid may have both primary (high voltage) and secondary (low voltage) distribution networks Figure 3.6 shows the distributed power system, where the legends are same as that in Figure 3.5.

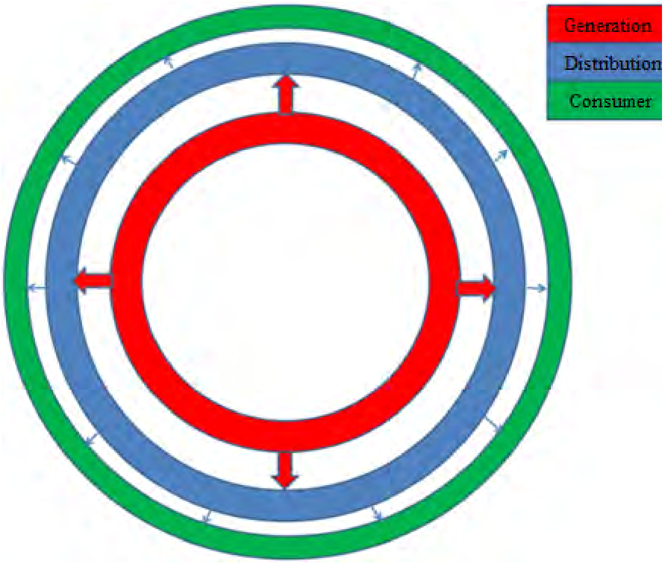


Figure 3.6: Distributed power system with distribution network only.

3.2 Microgrid

An electrical microgrid is local grid, which mainly operates within a small area, having no transmission network, only low level of voltage distribution network is available in a microgrid [7]. It can operate in an island mode or have a scope to be connected with national grid. The links between the idea of the national gird and the microgrid can be easily explained in similar way of links of a big market in an urban area with the small village market. The products may be either centrally generated or distributed or the products may be produced and consumed within a locality. The traditional microgrid may be expressed by the following circle diagram (Figure 3.7) where, the generation unit small and centralized.

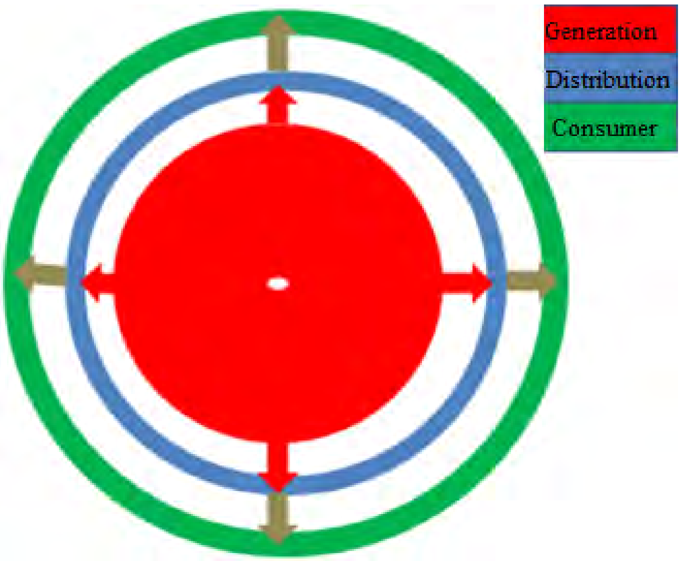


Figure 3.7: Traditional microgrid: having no transmission, only user voltage level of distribution. (Generation of power is centralized).

A microgrid is operating at Sandwip has the resources in a single unit. Figure 3.8 shows the solar PV- diesel microgrid structure at Sandwip Island. Details of this microgrid are included in Appendix –B.

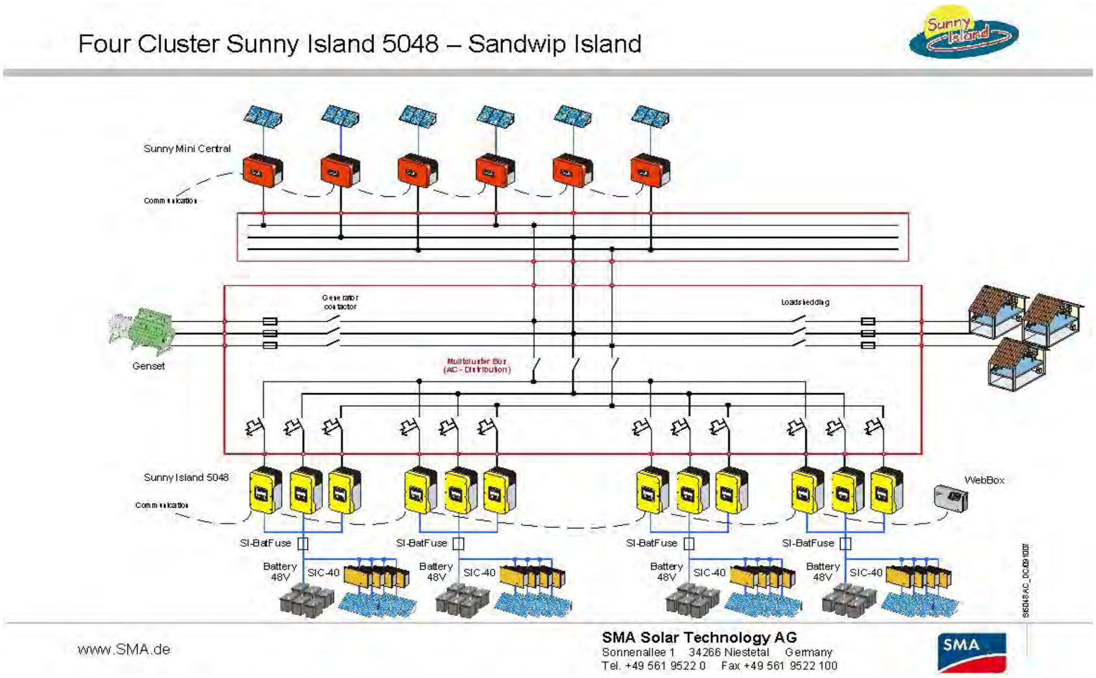


Figure 3.8: Solar microgrid layout using four cluster “Sunny Island” inverter.

However, the power sources of a microgrid may be decentralized as well. In fact, it has some advantages over a microgrid having central generation unit. There are multiple numbers of power units, which are distributed over the entire grid. Additions of new resources are easier to meet new increasing demand. This microgrid can be expressed by a similar circle diagram, of Figure 3.7. The several layers of a decentralized microgrid are shown in Figure 3.9.

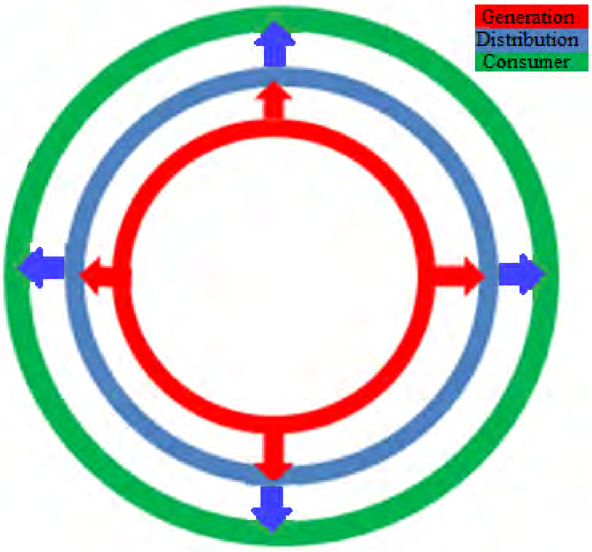


Figure 3.9: DER based microgrid where generation is distributed over the entire area.

3.3 Levels of Microgrid Based on Power Consumption

The microgrids may be categorized by the following ways Based on Power Consumption:

(a) Urban Microgrid: Yet, many of the urban area is not electrified. Urban microgrids are available there.
(b) Rural Microgrid: Thousands of rural microgrids are operating to electrify the rural markets and villages.
(c) Industrial Microgrid: a grid of self-powered industry.
(d) Remote Microgrid: 100kW$_p$ Sandwip Microgrid.
(e) Interconnected Microgrid: No microgrid is interconnected in Bangladesh.
(f) Islanded Microgrid: Most of the microgrids are islanded.

3.4 Why We Should Think of Distributed Generation

It is time to think of the distributed generation for several important reasons. These are summarized as follows:

(a) Higher installation cost, running and maintenance cost of centralized generation (CG).
(b) Loss and cost associated with transmission and distribution are high for CG.
(c) Fluctuations of voltage and frequency for CG.
(d) In CG, interruption at a node (generation, transmission or distribution) hampers a lot of consumers, thus less reliable
(e) Most of the generating stations in CG release carbon-di-oxide that is harmful for the environmental.
(f) Higher penetration of renewable energy is tough this.

3.5 Summary

Available microgrids in Bangladesh are mainly based on diesel generators. A few of them are based on biogas or other renewable energy sources. Whatever be the resources, the grids have small but central generation units. As the microgrids operate in a smaller region, people may in general think that the decentralized generations are less important. DER based larger grid are available in various parts of the world. However, a microgrid which has a scale suitable for Bangladesh must make use of the small-scale energy resources in a decentralized manner, which will prove to be more beneficial for Bangladesh. The next chapter will discuss the analysis and optimization of the available resources.

CHAPTER 4

ANALYSIS AND OPTIMIZATION OF THE AVAILABLE ENERGY RESOURCES

The last Chapter described the distributed energy resources and the microgrid. This Chapter describes the available renewable energy resources and its potential for Bangladesh. Among several renewable energy resources, the application of solar Photo Voltaic (PV) is more familiar though the largest plant based on renewable energy goes under hydroelectricity. Besides these, wind, biogas, mini hydro and tidal are also well known. GOB has a plan to generate 5% of the total energy from renewable energy resources within 2015 and 10% within 2020. Through the approved renewable energy policy, the GOB is committed to facilitate both public and private sector investments in renewable energy projects to substitute indigenous non-renewable energy resources and increase the contributions of renewable energy based electricity generation. With this context, analysis of the available renewable energy resources is essential. A new concept to maximize the energy usage from solar PV by changing the tilt angle and thus to minimize the shortage to meet a specific demand profile[1] of an isolated power system is also introduced here.

4.1 Available Renewable Energy Resources

The possible electricity generations from the renewable energy sources in Bangladesh are as follows:

(a) Solar
(b) Wind
(c) Small hydro
(d) Wave and tidal energy
(e) Biogas and
(f) Others

4.1.1 Solar

The sun is the source of all energy of the world. Wind, hydro, fuel, tidal and many other sources of energy directly or indirectly receive energy from sunlight. Sunlight is the light and energy that comes from the Sun. When this energy reaches the surface of the earth, it is called solar insolation. What we experience as sunlight is actually solar radiation. It is the radiation and heat from the Sun in the form of electromagnetic waves. Sunlight is a portion of the electromagnetic radiation given off by the Sun, in particular infrared, visible, and ultraviolet light. On Earth, sunlight is filtered through the atmosphere of the earth, and is obvious as daylight when the Sun is above the horizon.

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[1] Demand profile/pattern or load profile/pattern are used to express the same idea.

When the direct solar radiation is not blocked by clouds, it is experienced as sunshine, a combination of bright light and radiant heat. When it is blocked by the clouds or reflects off other objects, it is experienced as the diffused light.

Both light and heat of radiation can be used for our daily life. There are many ways to utilize the solar radiation such as direct heating of water, drying clothes, drying grains, generation of electricity etc. Generation of electricity may be accomplished by directly converting the light into electricity or using the heat energy as a source to boil the steam for a steam turbine. Solar power may be classified two categories, namely, solar thermal and solar photovoltaic (PV). However, only solar PV part will be discussed in this chapter for generating solar power.

The light energy of solar radiation can be converted into direct current of electricity by using a solar cell, which acts as the fundamental power conversion unit [28]. It is made from semi-conductor similar structure like diode. The solar cells are being made from different materials and different structure in the quest of maximum power with minimum cost. However, the efficiency of commercial cells is less than half of the value tested at laboratories. Among the several types of solar cell, poly-crystalline and mono-crystalline solar cells are mostly available. Besides these, amorphous and thin film solar cells are also available in the market [28].

Solar cells are arrangements of semiconductors to convert sunlight directly into electricity by exploiting photovoltaic effect. The incident energy of light creates mobile charged particles in the semiconductor, which are then separated by the device structure and used to produce electrical current.

4.1.2 Power loss in solar cells

The power losses in a solar cell may be discussed by fundamental loss, losses due to collection efficiency, series resistance losses and other losses. These are given below:

The fundamental losses
Not the entire solar spectrum is utilized for converting into usable energy. The rest of the energy may be considered as primary loss. The conversion efficiency may be improved by using Tandem cell. Loss as heat dissipation is also significant for solar cell. Besides these, loss due to recombination is also a factor to decrease the overall efficiency. This is an opposite process of carrier generation. Both Voltage and current reduces due to recombination thus the generated power from the PV cell [28].

Impurities or defects in crystal structure or at the surface of the semi-conductor may introduce energy levels inside the energy gap. These energy levels act as stepping stones for the electrons to fall back into the valance band and recombine with the hole thus reducing the carrier. Loss due to the ohmic metal contacts to the semi-conductor is also a fundamental loss. With proper structural development, these losses could be reduced.

Loss due to collection efficiency

Collection efficiency is defined as the ratio between the number of carriers generated and the number photon strikes the surface. Crystalline materials are good for achieving higher collection efficiencies. To increase the collection efficiency of amorphous or polycrystalline thin films are used. In this case, additional electric field are needed to pull the carriers [28].

Series resistance losses

Transmission of electric current produced by the solar cell involves with ohmic losses. This loss may be expressed by an equivalent resistance. This loss mainly reduces the fill factor[2][28].

Other losses

(i) Loss due to light reflection from the top surface: this can be minimized by anti-reflection coating and surface texturing

(ii) Loss due to shading of cells by top contacts such as fingers and bars: Stanford University has designed a new cell structure , where both of the contacts are moved to the back side.

(iii) Loss due to incomplete absorption of light: this loss could be minimized by using light trapping and making the back contact optically reflecting.

4.2 Effects of Temperature

Temperature has a negative co-efficient for voltage normally around -23mVK^{-1} for PV cells and positive co-efficient for current, which is very small and negligible [28]. These effects are shown in Figures 4.1.

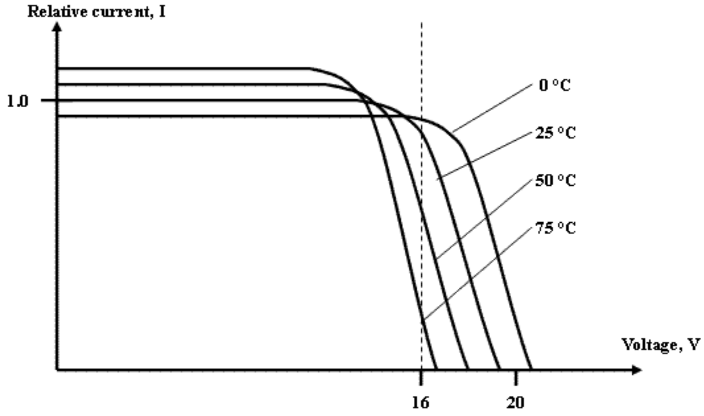

Figure 4.1: The effect of temperature on current vs voltage curve.

The generated power of a solar cell decreases with increase of temperature. The maximum power points for various temperatures also move towards the origin when temperature is increased [28]. This effect is shown in Figure 4.2

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[2] Fill factor=Maximum Power produced by the cell/(Short circuit current*Open circuit voltage of the cell)

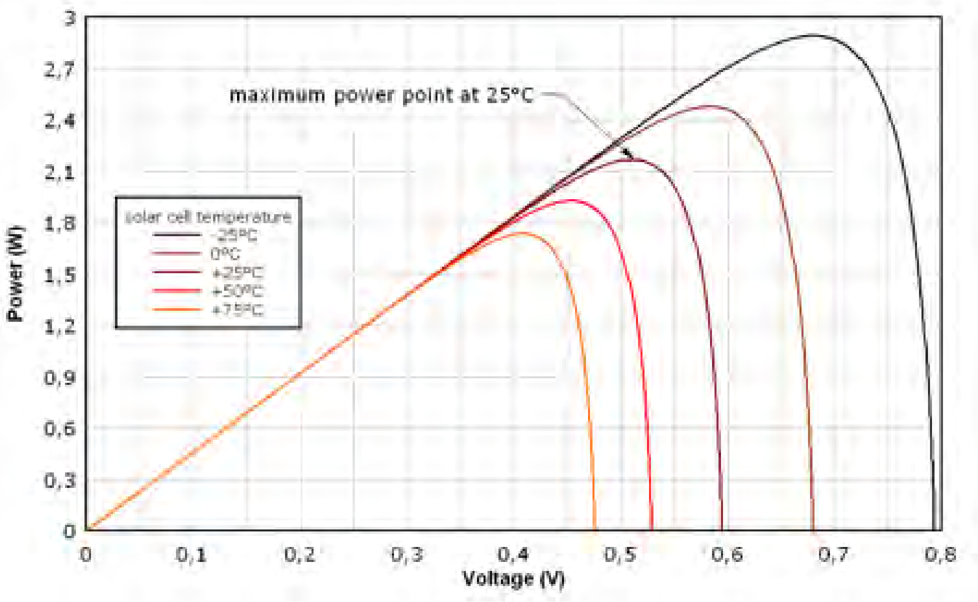

Figure 4.2: The effect of temperature on power vs voltage curve.

4.3 Effects of Irradiance

Short circuit current of a solar cell is directly proportional to the flux of photon with the band gap energy. The flux of photon increases with the irradiance. The irradiance has negligible effect on voltage. As a result, power is directly proportional to the irradiance of the radiation [28]. The effect of irradiance on current vs voltage curve is shown in Figure 4.3.

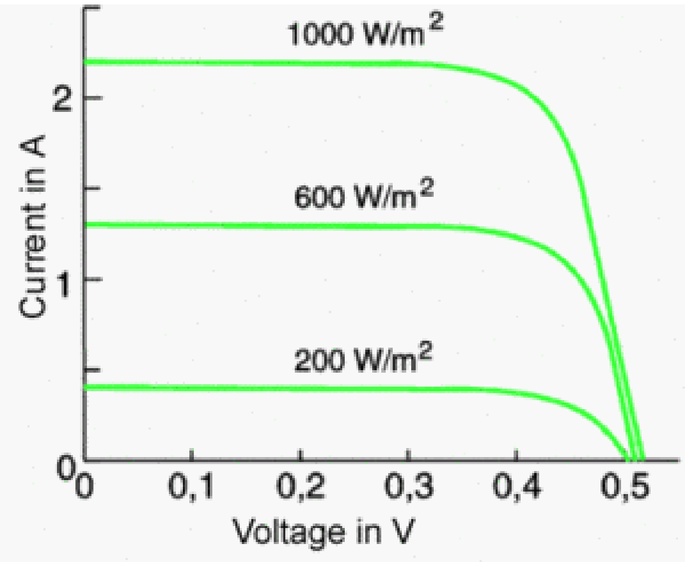

Figure 4.3: The effect of irradiance on current vs voltage curve.

The effect of irradiance on power vs voltage curve is shown in Figure 4.4.

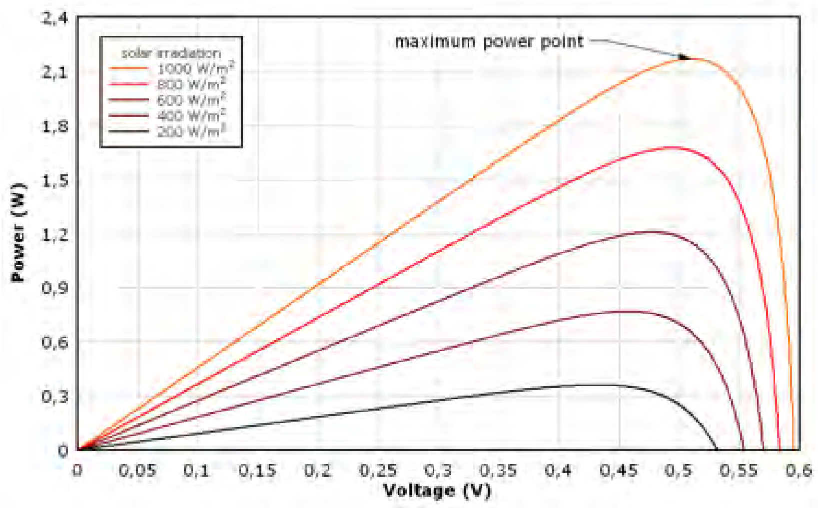

Figure 4.4: The effect of irradiance on power vs voltage curve.

The two curves are shown on the same plot in Figure 4.5

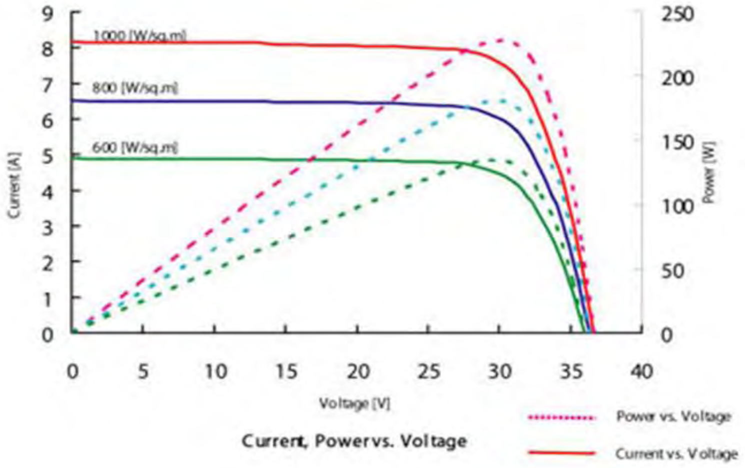

Figure 4.5: The effect of irradiance on power and current vs Voltage curve.

4.4 Effect of Angle of Incidence

Angle of incidence is an important factor. The number of incident photon is maximum when the incident ray is perpendicular to the plane of the solar panel. This can be described by the following equation.

$$I=I_o cos(\alpha) \ldots \ldots \ldots \ldots \ldots \ldots (4.1)$$

where,

α is the tilt angle, the angle between the incident ray and the area vector of the panel plane,

I_o= received irradiance when $\alpha=0^o$ and

I= received irradiance when $\alpha=other\ than\ 0^o$

As the sun seems to move from east to west, the angle of incident also varies with position of the sun. On the other hand, the position of the locus of the sun is also changed with the year round. Therefore, this is another reason for the change of the incident angle of the ray.

To have maximum power output from a solar panel, a maximum power point tracker is being used worldwide. Single axis sun tracker has been developed for better daily performance and dual axis sun tracker has been developed for better yearly performance. However, the cost associated with the sun tracker and the additional spaces that are required for panels‟ movement (inter panel distance) have almost nullified the better performance of the sun tracker.

4.5 Application of Solar PV in Bangladesh

The application of solar PV is mainly found in remote areas of Bangladesh. IDCOL started the SHS program in 2003 to ensure access to clean electricity for the energy starved off-grid rural areas of Bangladesh. The program supplements the Government‟s vision of ensuring „Access to Electricity for All‟ by 2021. Besides these, hybrid microgird (with solar PV), solar PV based irrigation system, grid-tied solar PV system are also in action. These are described below.

4.5.1 Solar Home System

In Bangladesh, access to energy services for cooking and lighting in off-grid villages is slender. Most rural households have to rely on kerosene lamps for lighting and traditional stoves for cooking. The Government has initiated various programs and has given enormous efforts to introduce flexibility in rural economy.

Solar power, especially SHS technology, has been accepted by the rural people in reasonable way to meet their lighting needs. More than 3 million SHSs have already been installed under the program in the off-grid rural areas of Bangladesh [3]. As a result, 13 million beneficiaries are getting solar electricity, which is around 10% of the total population of Bangladesh. IDCOL has a target to finance 6 million SHSs by 2017, with an estimated generation capacity of 220 MW of electricity.

At present 47 Partner Organizations (POs) are implementing this program. IDCOL provides refinancing and grant support as well as necessary technical assistance to the POs. The POs install the SHSs, extend credit to the end users and provide after sales services. IDCOL received credit and grant support from the World Bank, JICA and others financial supporting organization [3].

More than 65,000 SHSs are now being installed every month under the program with average year to year installation growth of 58%. The program replaces 180,000 tons of kerosene having an estimated value of USD 225 million per year. Moreover, around 70,000 people are directly or indirectly involved with the program. The program has been acclaimed as one of the largest and the fastest growing off-grid renewable energy programs in the world [3].

4.5.2 Solar diesel hybrid solution for telecom BTS

Higher cost of fueling and frequent maintenance let the telecom operators to think of running the remote and off-grid BTSs with an alternate power source. To provide uninterrupted voice and data services, a number of operators have decided to run off-grid BTSs with solar-diesel hybrid power systems. These systems use solar PV as the primary power source and diesel generator as backup. So far IDCOL has financed 138 such solar-diesel hybrid power solutions in the telecom sector [3].

4.5.3 Solar PV based irrigation system

Bangladesh has 14.76 million hectors of total land of which 8.3 million hectors are net cultivable and 7.56 million hectors are irrigable. It is an agro-based country whose irrigation is traditionally dependent on rain water. Besides this, irrigation pump has been considered as a major invention to ensuring food security. According to a survey conducted by Bangladesh Agriculture Development Corporation (BADC), there are about 1.42 million diesel operated irrigation pumps operating in the country, requiring about 1 million Tonne of diesel per year [19].

Solar powered irrigation system is an innovative, economic and environmental friendly solution for the agro-based economy of Bangladesh. This system mainly consists of solar panels and solar power operated pumps. Primarily, diesel operated shallow and low lift pumps, preferably using in triple crops areas, were targeted to be replaced by the solar irrigation pumps. Average capacity of each solar pump will be $8kW_p$ with a head of 12-15 meters. Area coverage will be on the average 13 hector of paddy fields per pumps. It is estimated that 18,700 diesel-based irrigation pumps will be replaced by solar powered pumps under this program. Total solar power capacity in this option will be 150 MW, which will reduce 95,000 litres of diesel and significant amount of CO_2 per day [19]. Till to date, around 46 numbers of pumps has been installed [3].

4.5.4 Solar PV based microgrid

Microgrid based on small diesel based generation is being used in Bangladesh. Yet many regions are out of the national grid. Many of them use microgrid to meet their electricity demand. Government has plan to install several microgrid based on solar PV. From this context, initially, 30 remote areas have been identified under this program where grid expansion is not planned for next 15-20 years. Additional new areas will be identified to develop solar mini grid system on the basis of successful implementation. Total solar power capacity in addition from this constituent will be 25 MW. Solar mini grid will ensure quality electricity in remote villages and help the villagers to have an improved income which will in turn elevate their poverty to some extent [3].

Besides these, BPDB, REB has installed larger size of solar PV systems in various locations of Bangladesh. IDCOL has installed 100-kW solar photovoltaic (PV) based micro-grid by PUROBI Green Energy Limited (PGEL) at Sandwip island in Chittagong. A 40-kW diesel generator has been integrated into the power plant in order to ensure adequate power supply during periods of low solar radiation [23].

IDCOL has a target to finance 50 solar mini-grid projects by 2017. The World Bank, KfW, GPOBA, JICA, USAID, ADB and DFID are providing financing support in these projects.

4.6 Other Renewable Energy Sources

Other than the solar PV, there are some other renewable energy sources available in Bangladesh. These are described in brief in sections 4.6.1 to 4.6.6.

4.6.1 Biogas

An agro-based country like Bangladesh has huge potential for utilizing biogas technologies. According to IFRD, there is potential of about four million biogas plants in our country. Grameen Shakti has completed installing 13,500 biogas plants. Recently Seed Bangla Foundation has proposed a 25 KW Biogas based Power Plant in Rajshahi. IDCOL has been implementing domestic biogas programs in Bangladesh since 2006 with support from SNV Netherlands and KfW. Till April 2014, IDCOL has financed construction of over 33,000 biogas plants all over the country through its 24 partner organizations. The program saves 80 thousand tons of firewood ever year worth \$2 million and also reduces the use of 28,000 tons of chemical fertilizer worth \$20 million by producing 200,000 tons of organic fertilizer. The program also reduces the use of 1,000 tons of kerosene every year. IDCOL has a plan to install 100,000 biogas plants in Bangladesh by 2018. Besides working in partnership with IDCOL, some organizations have constructed domestic biogas plants with their own funds. Moreover, since May 2011, IDCOL along with its partner organizations has installed 18,713 biogas plants in different parts of Bangladesh [3]. Besides these, Biomass production from rice husk energy (similar process to biogas) is steady over decade and day by day it is showing an increasing trend [24].

4.6.2 Hydro energy

The Karnafuli Hydro Power Station is the only hydropower plant in the country (located at Kaptai, about 50 km from the port city of Chittagong), having a capacity of 230 MW by 5 units. It is operated by BPDB which is considering the increase of production up to 330MW. Two sites have been chosen for other two Hydro power plants at the Sangu and Matamuhuri rivers, one named The “Sangu Project” (140MW) and the other “The Mata-muhuri Project” (75MW). The Water Development Board (BWDB) and BPDB carried out a joint study on micro-hydro power potential in the country [4]. A 50 kW micro-hydro plant was installed at Barkal Upazila of Rangamati district in 2005. The ongoing projects are: 50-70 kW Mohamaya Irrigation-cum-Hydro Power Project at Mirersorai, Chittagong. Rehabilation of 50 kW micro-hydro power plant at Barkal Upazila of Rangamati district is underway [16].

4.6.3 Wind

The potential of wind energy is limited to coastal areas, off-shore islands, rivers sides and other inland open areas with strong wind regime. In order to generate electricity from wind energy, BPDB installed 4x225 KW = 900 KW capacity grid connected wind plant at Muhuri dam area of Sonagazi in Feni. Another project of 1000 KW wind-battery hybrid power plant at Kutubdia Island was completed in 2008, which consists of 50 wind turbines of 20 kW capacity each.

Repair work of the existing 900 kW grid connected wind power project at Muhuri dam of Sonagazi in Feni is going on. Repair and operation and maintenance of the existing Kutubdia 1000 kW wind-battery hybrid power Project is underway. Steps have been taken to install 15 MW wind power plant across the coastal regions of Bangladesh after a year wind resources assessment in Muhuri dam area of Feni, Mognamaghat of Cox“sbazar, Parky beach of Anwara in Chittagong, Kepupara of Borguna and Kuakata of Patuakhali. Wind mapping is going on at Muhuri dam area of Feni and at Mognamaghat of Cox“s bazar by “Regen Powertech Ltd.” of India.

Installation of wind monitoring stations at Inani beach of Cox'sbazar, Parky Beach of Anwara, Sitakundu of Chittagong and at Chandpur under USAID TA project is also underway[4].

4.6.4 Ocean wave energy

Ocean wave energy is another special type of renewable energy, which is generated directly from the waves of the oceans and thus helps decrease the harmful emissions of greenhouse gases associated with the generation of power. It can be potentially a significant source of generating electricity for Bangladesh. Though the main purpose of ocean wave energy is electricity generation, it can also be used for pumping of water and desalination of water as well.

“The Oscillating Water Column method” is technically feasible and proving very attractive for this purpose. This type of wave energy harnessing device is being commissioned by several countries such as the United Kingdom (500 kW), Ireland (3.5 MW), Norway (100 kW) and India (150 kW). Bangladesh has a good potential for harnessing ocean wave energy from the Bay of Bengal [24].

4.6.5 Tidal energy

Tidal energy is a form of hydropower that converts the energy of tides into electrical power. As tides are more predictable than wind and sunlight, tidal energy can easily be generated from the changing sea levels. The coastal area of Bangladesh has a tidal rise and fall of between 2 to 5 meters. Among these coastal areas, Sandwip has the best prospect (more than 5 meter tidal rise fall) to generate tidal energy [25]. Bangladesh can generate tidal power from these coastal tidal resources by applying low and Medium head tidal movements. Low head tidal movements which uses tides of height within 2m to 5m can be used in areas like Khulna, Barisal, Bagerhat, Satkhira and Cox's Bazar regions and the high tidal movements which use more than 5m of tidal wave can be mainly used in Sandwip. Therefore, we can say that with suitable tidal height available, this can be a great source of electrical energy for Bangladesh.

4.6.6 Geothermal energy

Bangladesh shows the prospect to explore the geothermal resources in the northern districts. Dhaka-based private company, namely, „Anglo MGH Energy‟ has initiated a project to setup the country‟s first geothermal power plant with a capacity to produce 200 MW of electricity close to Saland in Thakurgaon district [25] . They have planned to set up 28 deep tube wells to lift hot steam and the lifted steam will be used to run a turbine and the turbine is connected to the generator to generate electricity. From the above discussion, it is clear that geothermal energy can also be a great source of harnessing electrical energy in Bangladesh.

4.7 Parameters for Choosing a Renewable Energy Resource

There are some parameters which should be considered for choosing a renewable energy resource. Among them, geographical location plays a significant role in selecting proper renewable energy resources. Different areas of the Earth receive different amounts of sunlight based on the location, the time of year, and the time of day. A suitable location for installing solar panels has specific characteristics and requirements. Identification of those locations requires that desirable characteristics be defined first. With an ideally suitable site, a solar panel should be placed south faced and a 23.5^{o} tilt angle (in average) with the horizontal plane in Bangladesh. The site should be chosen such that it may receive adequate amount of sun light.

The coastal area of Bangladesh is mostly protected by the trees. However, sometimes we may have to cut the trees of the coastal area to ensure exposure of adequate sunlight on the installed panel. Rivers are open space and receive plenty of solar radiation. However, orientation is important for the installation if that is on a boat or anything movable. It is better to install the panel on any boat or roof-top of an electric car horizontally. In hilly regions, special care should be taken to install interconnection of solar panels/power sources.

Population is another parameter which determines the effectiveness of utilizing a renewable energy resource. In highly dense urban areas where high-rise buildings are common, panel should be chosen for high shadow effect. In these areas interconnected solar system with storage is preferable. Where energy demand is high, there high efficiency solar panel with hybrid system is needed. In low density areas, standalone system is better due to per capita inter-connection cost.

Special care should be taken while installing PV panels at the coastal area for two reasons: firstly to protect them from cyclones and secondly without cutting any trees. Therefore, PV cells should be placed carefully considering all the parameters. Installation of solar PV at the coastal area may hamper the environment because of cutting the overhead trees.

Wind is not always a steady source of energy. Wind speed changes constantly, depending on the time of day, weather, and geographic location. Wind farms can be

found near farmland, in narrow mountain passes, and even in the ocean, where there are steadier and stronger winds. Wind turbines are suitable in the coastal areas considering the flow of wind. However, wind farms are not suitable in densely populated areas.
Bangladesh is a plain delta having three of the major rivers of the world namely, the Ganges, the Brahmaputra and the Meghna flowing through it. The Jamuna-Padma,-Meghna river system divides it into east and west zones and creates an average water flow of 1.3 trillion m^3 in a year throughout the country. Many other rivers flow throughout the country which are actually the tributaries of these rivers. During monsoon, the flow rates of most of the rivers are high but it reduces substantially during winter. Hence the scope of hydropower generation is very limited in Bangladesh, except in some hilly regions in the northeast and southeast parts of the country. However, there are a lot of tributaries, canals, tiny waterfalls which have good potential for setting up hydro power plants. Hydro power plants convert the hydro power of the fluid into mechanical power which is further converted to electrical energy. Many types of hydro power plants can be setup according to the generation capacity.

Bangladesh has a wonderful climate for biogas production. The ideal temperature for biogas is around 35ºC. The temperature in Bangladesh usually varies from 6ºC to 40ºC and also the raw materials for biogas are easily and cheaply available everywhere in the country [25]. Bangladesh is an agricultural land. Therefore, biomass is available in a huge proportion. Cow dung, agricultural residue, poultry dropping, water hyacinth, rice husk etc. are available in Bangladesh for biomass power generation. Biogas plants are more effective in densely populated areas.

Small wind turbines can be installed in the coastal area and off-shore islands of the country. Also micro hydro power plants can be installed in the north-eastern hilly regions and in the existing irrigational canal system with sufficient head.

There are scopes of installing integrated small tidal power plants in the coastal area. Wind plants should be placed in a less density area or in an open area.

4.8 A Systematic Approach for Finding the Optimum Tilt Angle for Meeting the Maximum Energy Demand.

The panel is ideally kept at a tilt angle equal to its latitude, which is about 23.5^0 (in average) for Bangladesh. This gives an overall higher output for electricity generation over the year. However, considering the load profile over the year, the best performance may not be found at the default latitude angle.

This is an important analysis for maximizing the utilization of the output. For smaller and isolated system, the surplus energy is not utilized normally. On the other hand, shortages are to be met by an alternate approach. By changing the tilt angle, it is possible, to some extent, to shift the surplus energy to the season when there is shortage. The following analysis is targeted to have the minimum shortage maximizing the demand met for an isolated system.

4.8.1 Method of determing the optimum tilt angle

As the system is isolated, there is no scope of utilizing the surplus beyond the demand profile, and the shortage must be met by an alternative source. The surplus energy can not be stored for long time for seasonal use. The analysed figure (Figure 4.11) shows that during November to April of a year has a surplus and June to July has a remarkable shortage. However, it is technically and economically not feasible to store the surplus of one season to use it for another season. It has been found that, by changing the tilt angle, it is possible to shift the curve to a suitable position, where the energy demand will be met maximum.

It has been noticed that the generation is lower at June to september and higer for october to May. By changinng the tilt angle it is possible to have higher generation during June to september, where the demand is higher, thus the shortage can be minimized. However, the surplus will also become less, but is not a factor for an isolated system at all. The choice of a suitable tilt angle for installing the solar panel will be discussed now. To understand the effect of changing the tilt angle, the sun path daigram is described here with the help of Figure 4.6.

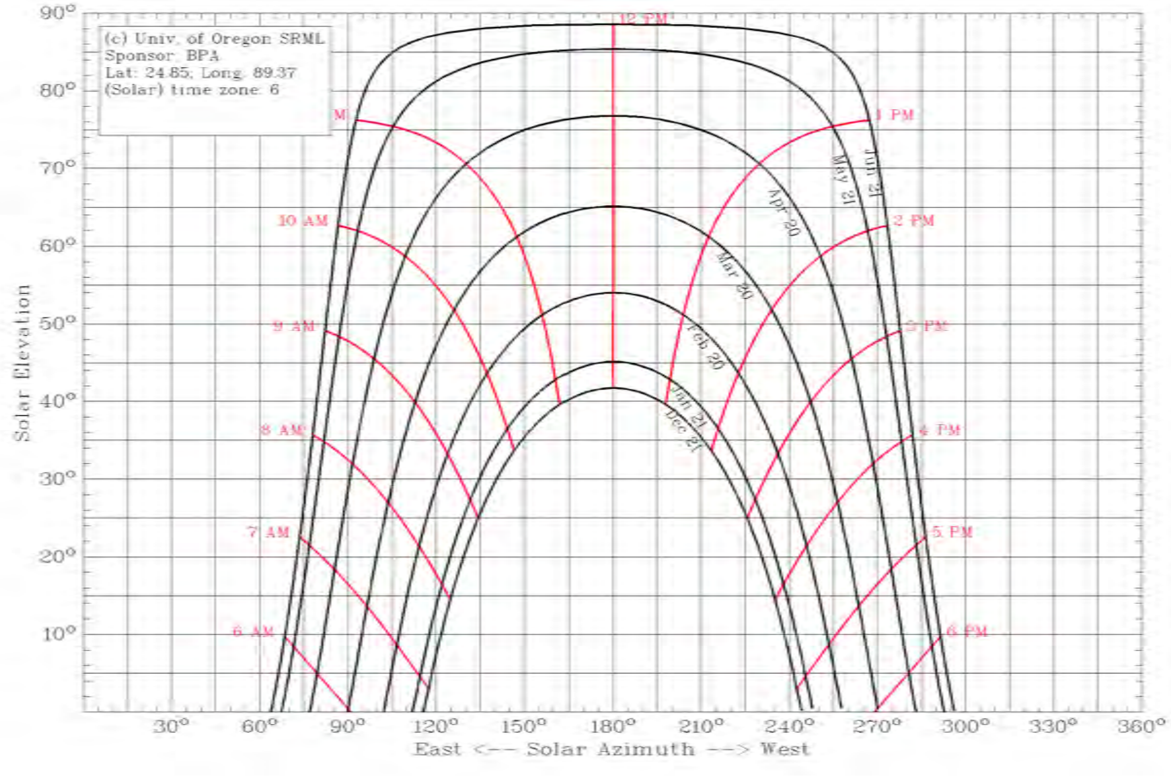

Figure 4.6: Sun path diagram for Bangladesh.

The sun path diagram shows the locus of sun over the year for various months. This is generated for a latitude of 24^0 and the longitude of 90^0 (for Bangladesh, generated by given online software of University of Oregon). The elevation of the sun varies from 43^0 to 89^0 for the variation of winter season to summer season. The winter has a shorter range of azimuth and the summer has a longer range of azimuth. As a result, the winter has a shorter day than night and the summer, a longer day than night. For this reason the winter should have the lower generation and summer should have the higher generation. The maximum power at the winter (December 21) will be generated at the tilt angle of $(90^0-43^0)=47^0$ and for the summer season (June 21^0) it will be at $(90^0-89^0)=1^0$degee. For the rest of the days of the year, the tilt angle at which the maximum power occurs, varies from 1^0 to 47^0. For maximum energy generation over the year the tilt angle is taken averagae of the both the extremeties (1^0 and 47^0), which is 24^0 for this example.

However, here is an important point to think that due to changes in temperature, changes of irradiance due to cloud, fog, rain over the year, the output is not directly proportional to the duration of the day, rather it depends on the total solar insolation (total energy per square meter within a fixed duration) of the day. The total output for a solar PV panel could be found by using the "PVwatt" database, which is an online database software provided by the National Renewable Energy Lab (NREL) [26], Canada. NREL has 08 observation points for Bangladesh- Bogra, Chittagong, Cox"s Bazar, Dhaka, Ishwardi, Jessore, Rangpur and Sylhet. The outputs of a 1kWp solar PV panel at different locations of Bangldesh at its default tilt angle (latitude of 23.5^0) is shown in Table 4.1.

Table 4.1: The outputs of a 1kWp solar PV panel at different location of Bangldesh at its default tilt angle (latitude).

Station Name	**Bogra**	**Chittagong**	**Cox's Bazar**	**Dhaka**	**Ishwardi**	**Jessore**	**Rangpur**	**Sylhet**
Default Tilt angle	**24.9°**	**22.3°**	**21.4°**	**23.8°**	**24.1°**	**23.2°**	**25.7°**	**24.9°**
January	113	126	129	116	112	116	108	110
February	107	114	118	112	109	110	110	103
March	125	132	134	122	124	126	126	119
April	122	120	125	116	119	122	119	109
May	112	114	113	107	113	113	99	97
June	96	94	86	90	89	92	85	78
July	86	88	79	85	86	91	77	75
August	91	101	90	93	89	93	84	77
September	91	96	98	97	90	91	81	81
October	107	107	118	109	108	109	107	99
November	106	110	114	105	111	107	114	109
December	111	123	123	112	115	120	112	113

The corresponding irradiance of different locaation of Bangladesh is shown at Table 4.2.

Table 4.2: The availabe irradiance at different location of Bangldesh

Station Name	Bogra	Chittagong	Cox's Bazar	Dhaka	Ishwardi	Jessore	Rangpur	Sylhet
Default Tilt angle	**24.9°**	**22.3°**	**21.4°**	**23.8°**	**24.1°**	**23.2°**	**25.7°**	**24.9°**
January	5.32	5.84	6.00	5.47	5.19	5.43	5.02	5.09
February	5.64	5.99	6.16	5.91	5.74	5.77	5.80	5.36
March	6.13	6.21	6.47	6.00	6.03	6.00	6.09	5.68
April	6.19	5.95	6.25	5.85	6.11	6.12	6.00	5.42
May	5.44	5.43	5.46	5.23	5.51	5.49	4.84	4.70
June	4.83	4.67	4.30	4.55	4.48	4.56	4.32	3.95
July	4.19	4.18	3.78	4.18	4.15	4.38	3.74	3.70
August	4.40	4.76	4.27	4.60	4.32	4.46	4.13	3.79
September	4.61	4.77	4.87	4.94	4.56	4.57	4.09	4.14
October	5.25	5.23	5.71	5.44	5.35	5.35	5.16	4.89
November	5.28	5.53	5.73	5.34	5.43	5.19	5.56	5.41
December	5.22	5.76	5.80	5.38	5.37	5.59	5.21	5.31

However, the output also depends on the tilt angle. If the tilt angle is greater (>23^0) than the default tilt angle (lattitide), the PV panel will generate more energy at winter and less energy at summer than those for the default tilt angle. For an angle smaller than (<23^0) than the default tilt angle (lattitide), the the PV panel will generate less enerrgy at winter and more energy at summer than those for the default tilt angle. By changing the tilt angle, it is possible to have closer generation pattern[3] to that of the demand pattern. The output of a 100kW_p PV panel for vaious tilt angle, considering the installation at Dhaka region, is shown in Table 4.3.

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[3] Generation profile and generation pattern are used to express same idea

Table 4.3: The outputs of a 100kWp solar PV panel at different tilt angle, location is chosen as Dhaka

TiltAngle	January	February	March	April	May	June	July	August	September	October	November	December
28	11951	11382	12180	11415	10420	8677	8234	9145	9648	11042	10763	11578
27	11882	11349	12182	11455	10486	8746	8291	9189	9665	11019	10708	11500
26	11810	11313	12181	11492	10549	8812	8345	9230	9680	10994	10651	11420
25	11735	11275	12177	11527	10610	8877	8399	9270	9692	10966	10591	11336
24	11657	11232	12170	11559	10669	8941	8450	9307	9702	10935	10528	11248
23	11576	11189	12161	11589	10726	9002	8500	9343	9710	10902	10462	11157
22	11492	11143	12149	11616	10781	9062	8547	9377	9716	10866	10393	11063
21	11404	11094	12135	11640	10833	9121	8593	9408	9719	10826	10322	10967
20	11314	11043	12118	11662	10883	9177	8638	9438	9720	10784	10248	10867
19	11220	10989	12098	11681	10931	9232	8681	9466	9720	10738	10171	10763
18	11122	10932	12075	11698	10977	9285	8722	9491	9717	10691	10092	10657
17	11021	10872	12049	11712	11020	9335	8761	9515	9712	10642	10010	10548
16	10916	10810	12021	11724	11061	9384	8798	9536	9705	10589	9925	10435
15	10808	10745	11990	11733	11100	9431	8834	9556	9696	10534	9836	10315
14	10695	10677	11956	11739	11137	9476	8868	9574	9684	10476	9744	10193
13	10576	10607	11920	11743	11172	9519	8899	9589	9671	10416	9650	10066
12	10456	10534	11881	11744	11206	9560	8931	9603	9655	10352	9553	9935
11	10333	10457	11839	11743	11235	9599	8959	9615	9637	10286	9454	9802
10	10209	10378	11794	11739	11262	9637	8986	9624	9617	10217	9352	9666
9	10082	10295	11746	11732	11287	9671	9010	9631	9594	10144	9249	9527
8	9952	10211	11696	11723	11309	9704	9032	9637	9570	10069	9144	9385
7	9819	10124	11643	11711	11329	9734	9053	9640	9543	9991	9036	9242
6	9682	10034	11587	11696	11346	9762	9072	9641	9514	9910	8925	9096
5	9543	9942	11529	11679	11361	9786	9089	9640	9483	9828	8812	8948

4.9 An Optimization Routine Based on MATLAB

A MATLAB based optimization routine has been developped to find out the optimum tilt angle, where the demand will be met to its best possible match. The following key features were adopted in formulating the optimization routine.

1. First, the total yearly demand profile from the data of PGCB (last three years) has been extracted. A similar demand profile has been made for 100 numbers of typical village families.
2. Next, the approximate size of the solar PV panel need is obtained by dividing the yearly total the demand by total produciton of 1kWp solar panel. It is rounded to the nearest integer for ease of the calculation. Let, the rated capacity found from this calculation is denoted as “cap”.

3. Then, the total yearly generation of the energy by “cap” (the installed size) is found for various tilt angle from Table 4.3.
4. When demand is greater than the generation, it is considered shortage otherwise it is surplus. Thus both shortage and surplus are found for various tilt angles.
5. The maximum demand is met when the shortage is minimum.
6. The tilt angle for which the maximum demand is met is then found out.
7. For a more real approximation, a random function is included for both the demand profile and generaion profile as follows:

II. *random_demand=demand*(1-r+2*r*rand())…………….(4.2)*

III. *random_generation=generation*(1-r+2*r*rand())……..(4.3)*

IV.

V. These will assign +r% to –r% value of the demand or generation given at the look up table.

1. Owing to the insertion of a random factor, the tilt angle at which the maximum demand is met, now varies slightly in random fashion.
2. This iteration runs for n (we used n=1000) times.
3. The frequency of satisfying the condition for meeting the maximum demand is found for various tilt angles.

4.10 Analysis for National Load Profile and PV Generation in Dhaka

The analyzed results based on the procedure describes in the previous section are shown in Figure 4.7 – Figure 4.13. In this case, demand profile has been considered similar to that of national grid and generation profile is connsidered for the region of Dhaka. Figure 4.7 shows the total generation (thus consumption) of Bangladesh for the last three years and the average value of them. The months are indicated by the index of the months from 1 to 36. The MATLAB implementation routine is included in Appendix-C.

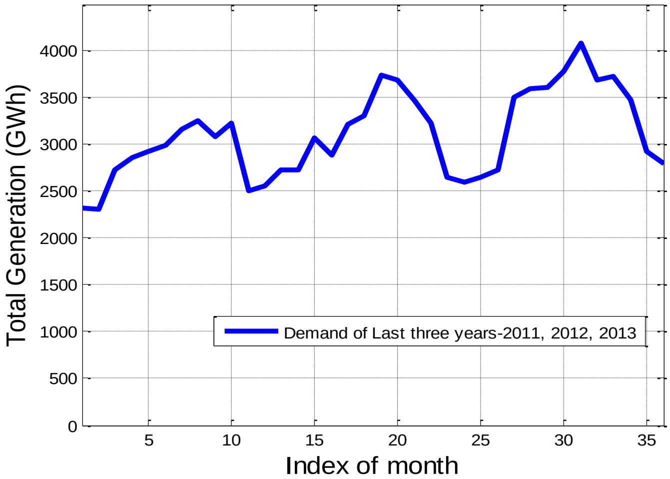


Figure 4.7: The total generation of Bangladesh for the last three years (2011~2013).

The demand has been analysed to find out the demand pattern. Figure 4.8 shows the total generation (thus consumption) of Bangladesh for the last three years and the average value of them.

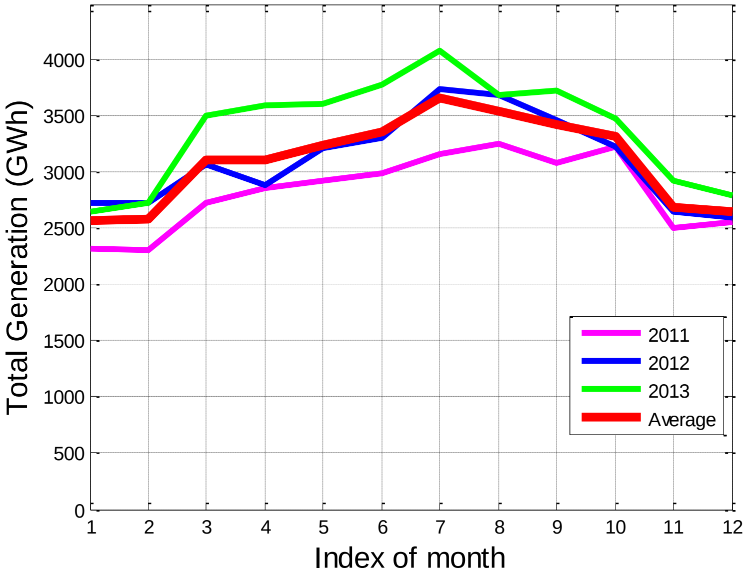


Figure 4.8: Total monthly generation of last three years (2011~2013) and the average.

For a clear view of the averagae demand pattern, the average of the last three years is shown in Figure 4.9.

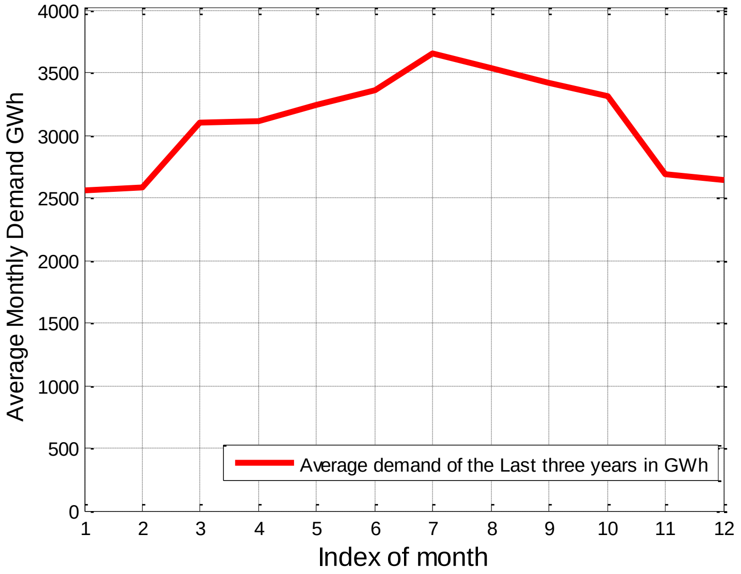


Figure 4.9: Average monthly demand pattern.

For a realistic analysis, a system has been considered with a set of 100 typical families of a remote village, where the average consumption is around 50KWh per month. The demand pattern of the group of the users has been assumed to be similar with the national grid ddemand. Thus, the possible demand of the system may be shown as in Figure 4.10.

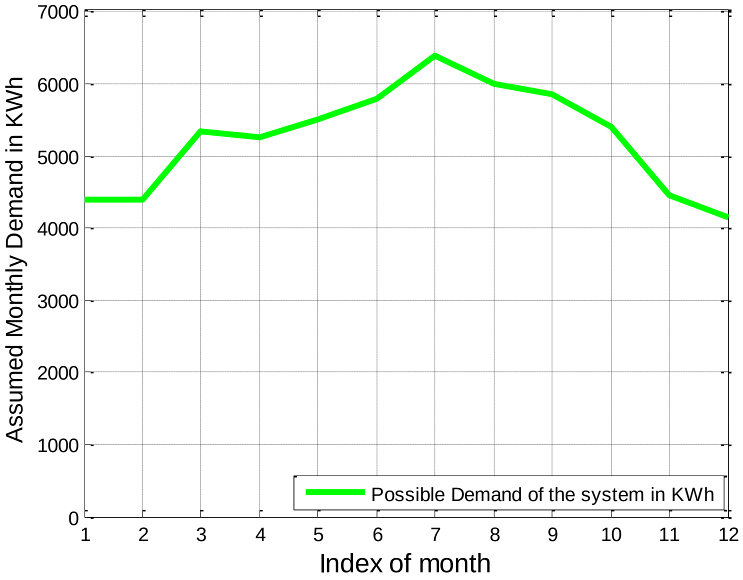


Figure 4.10: A system demand for a set of 100 typical village family (Similar to the national demand profile).

For the best meet of the demand by the electricity generated from the solar PV, the generation pattern of the solar should be best match with the demand pattern. Normally a panel is fixed at the default tilt angle. Monthly generation of a 50 KWp solar PV panel at the default tilt angle is shown in Figure 4.11, where the demand pattern is also shown in the same figure.

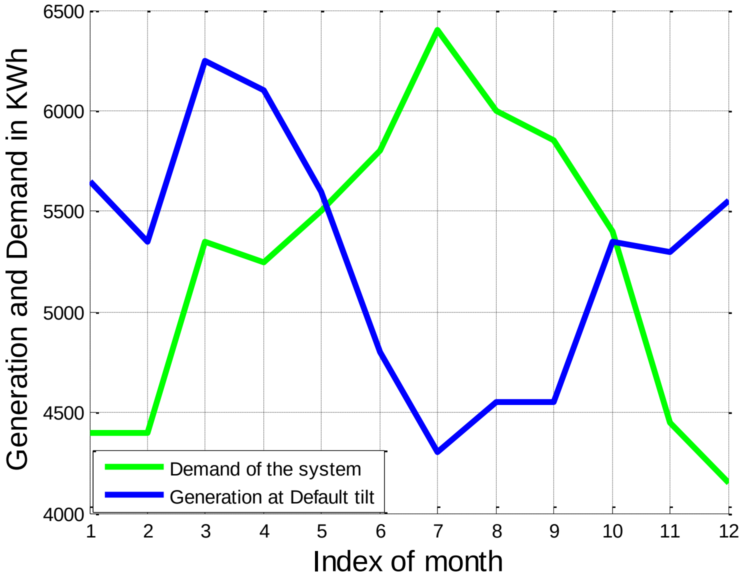


Figure 4.11: Generation and demand pattern of the considered system.

The avobe figure clearly shows that, the demand pattern and the generation pattern are not same. Surplus electricity for the months November to April could not be utilized at the time of shortage (May to October) by storing it in storage (battery, ot others). As the system is assumed as an isolated grid the axcess electricity could hardly be utilised beyond the demand profile in any way. It is possible to change the generation pattern by changing the tilt angle Therefore, less shortage and less surplus could be achieved. The model has been developed to find the tilt angel at which the both of the pattern match their best and also the generation is also enough.

For the avobe condition of demand pattern and generation pattern, it is found that the maximum power consumption or maximum demand is met around the angle of 11^0 and 12^0. However, as both of the demand and generation pattern may vary, the appropriate angle for maximum utilization condition also may be changed. Using the variation within +r% to – r% of the demand pattern and generation pattern (shown in 4.11), the appropriate tilt angle may be found. However, as the variation is random, the found angle will also vary randomly. For this reason, several numbers (1000) of iteration has been done. The results are shown in the next figures for various random variations.

Figure 4.12 Figure 4.13 show the results when the random variation is 0.01% and 0.1% respectively. The minimum shortage occurs only at 11^0 and 12^0. The vertical axis shows the titl angle, and the horizontal axis shows the number of occurance for several tilt angles, when the "maximum demand met" condition is satisfied and where the shortage becomes minimum.

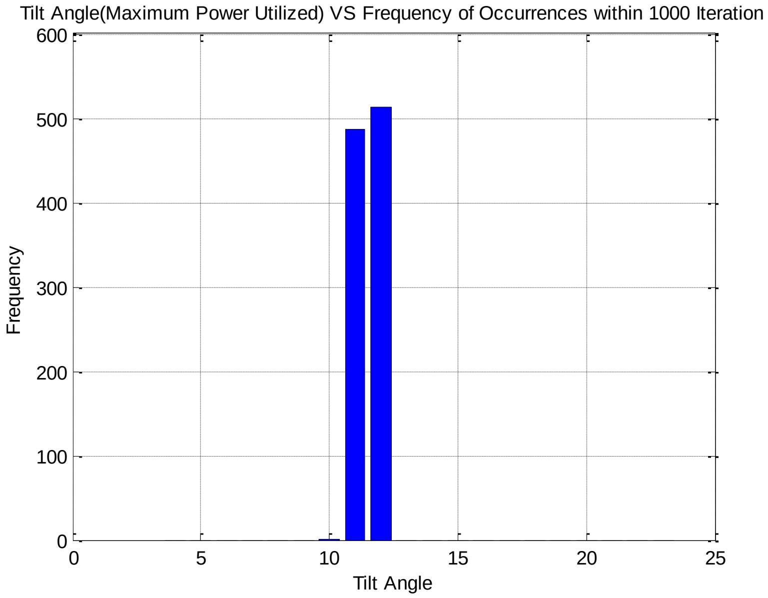


Figure 4.12: The frequency of maximum occurrence of minimum shortage for r=0.01%.

Around 480~490 times out of 1000 itteration, the maximum utilization occurs at 11^0 and 510~520 time out of 1000 itteration, the maximum utilization occurs at 12^0.

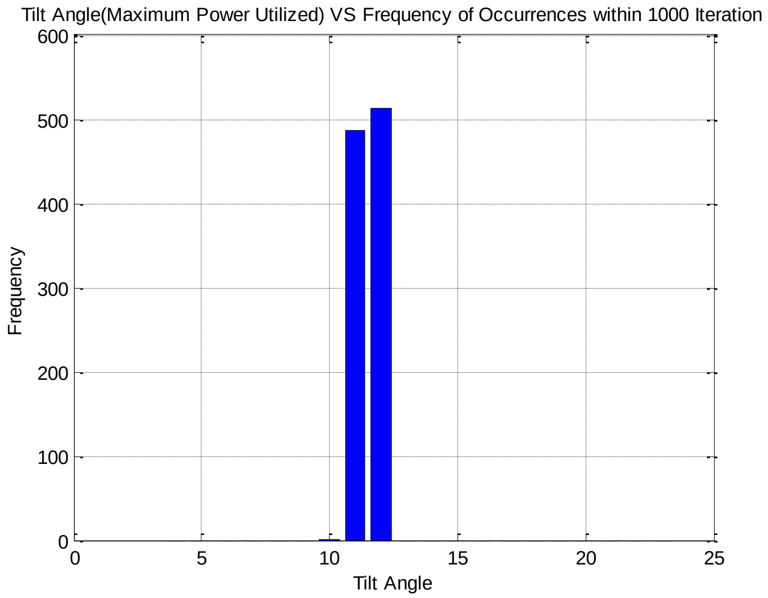


Figure 4.13 : The frequency of maximum occurrence of minimum shortage for r=0.1%.

For 1% random variation, in most of the cases, the minimum shortage occurance appears at 11^0 and 12^0, which are shown in Figure 4.14. As the magnitude of the variation increases, the tit angle at which maximum utilization occurs, also varies from 11^0 and 12^0.

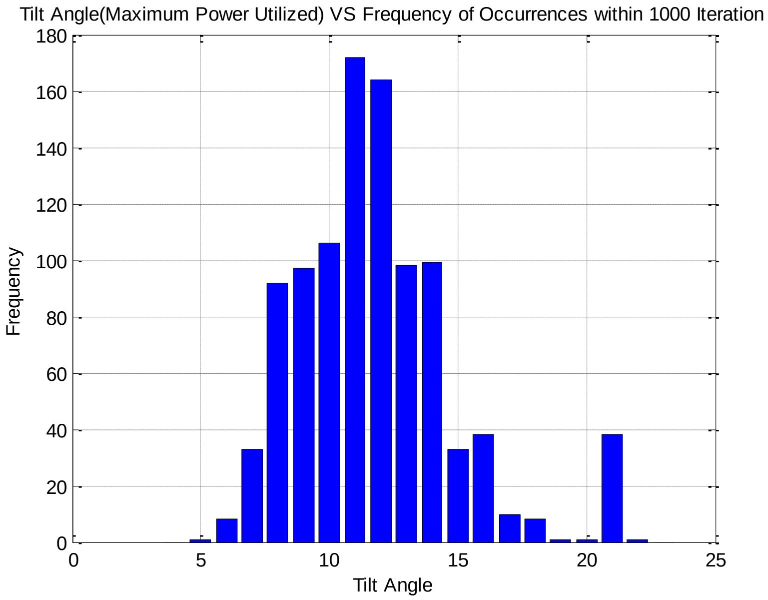


Figure 4.14: The number of maximum occurrence of minimum shortage for r=1%.

For larger variation of the demand and generation such as for r=2%, 5%,and 10%, the number of maximum occurance is still found to be around 11^0 and 12^0. These are shown in Figure 4.15 to Figure 4.17.

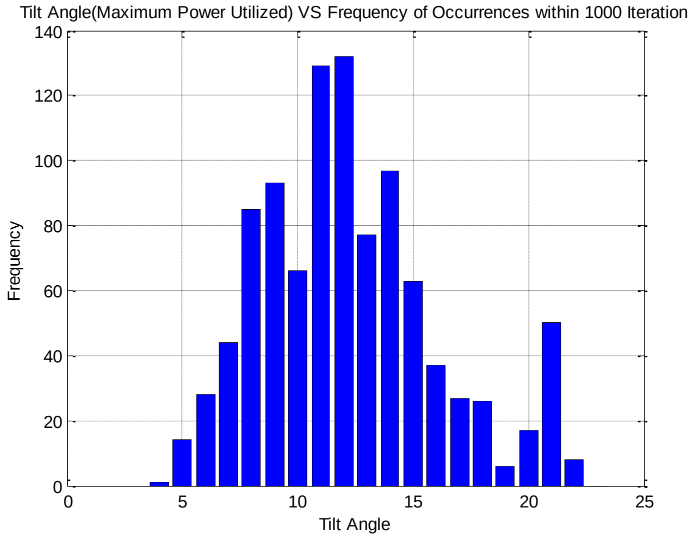


Figure 4.15 : The number of maximum occurrence of minimum shortage for r=2%.

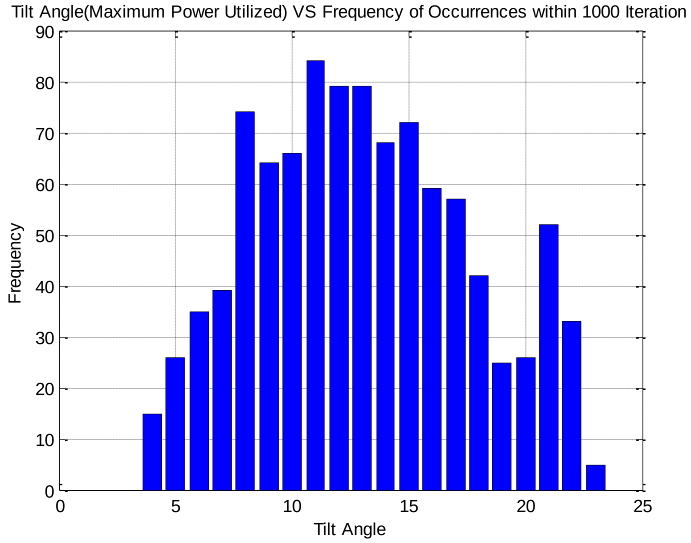


Figure 4.16: The number of maximum occurrence of minimum shortage for r=5%.

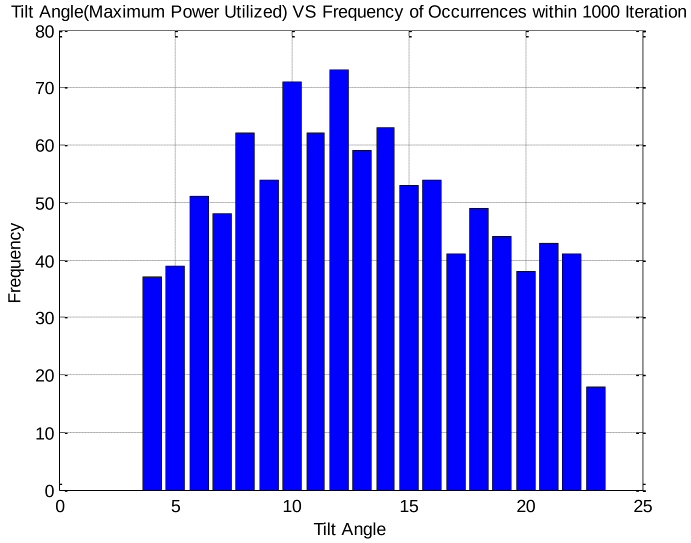


Figure 4.17: The number of maximum occurrence of minimum shortage for r=10%.

From the above analyses, it can be deduced that utilization of maximum energy for a region may not be generated at a tilt angle of the default latitude. The default latitude will produce the maximum energy over the year, but maximum utilization of power will depend on tilt angle as well as the demand profile over the year. Considering a demand profile similar to the national demand profile of Bangladesh and generation profile same as Dhaka, the minimum shortage occurs for most of the time at a tilt angle of 12^0 and around it. The demand, generation and surplus/shortage for 23^0 and 12^0 tilt angles are shown in Figure 4.18.

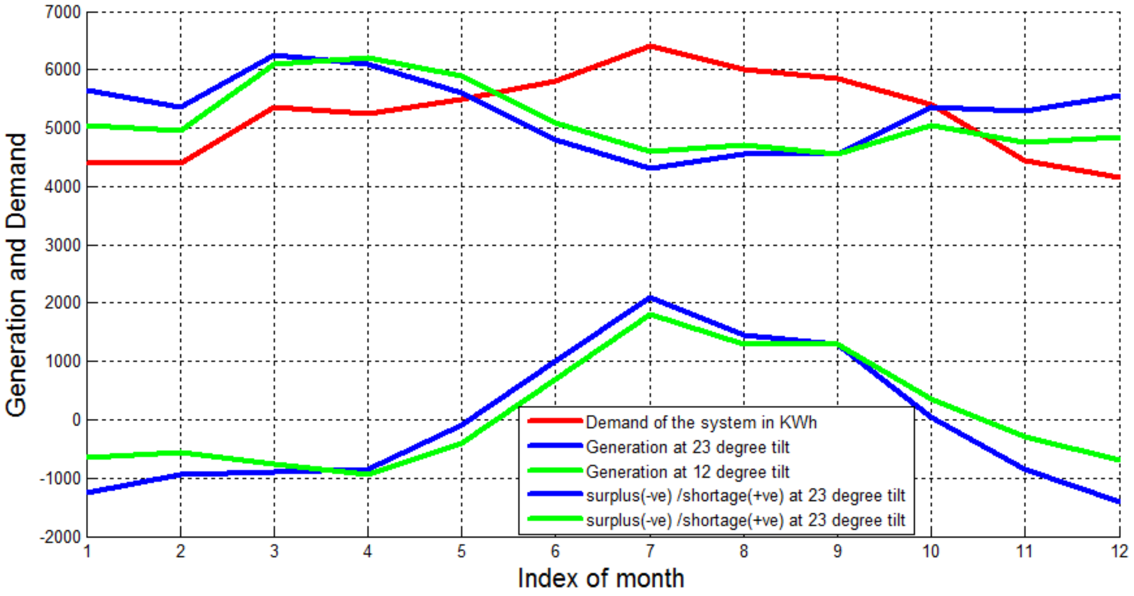


Figure 4.18: The demand, generation and surplus/shortage for 23^0 and 12^0 tilt angles.

The above analysis shows the result of an optimum angle at which the demand will be met for the highest amount. In this analsysis, the demand pattern is taken similar to that of the national grid and the generation profile of Dhaka. And it is found that the opimum tilt angle for maximum demand met is around 12 degree. However, the result may vary for other load pattern as well.

4.11 Analysis for Sandwip

To evaluate the performance of the developed model, demand profile and generation profile of various location should be taken in account. In this context, the location has been chosen as Sandwip, Chittagong, an isolated island. Analysis of this grid will provide more acceptable result for this program. In this analysis, the demand profile of several types of users of currrently running solar PV-diesel hybrid microgrid in Sandwip has been taken in account. The results of these analyses are shown in Figure 4.19 – Figure 4.28. The MATLAB implementation routine is given in Appendix-C. Figure 4.19 shows the consumption pattern of several types of user for the last three years (2011, 2012 and 2013).

Figure 4.19: The consumption pattern of several types of user for the last three years (2011, 2012 and 2013)

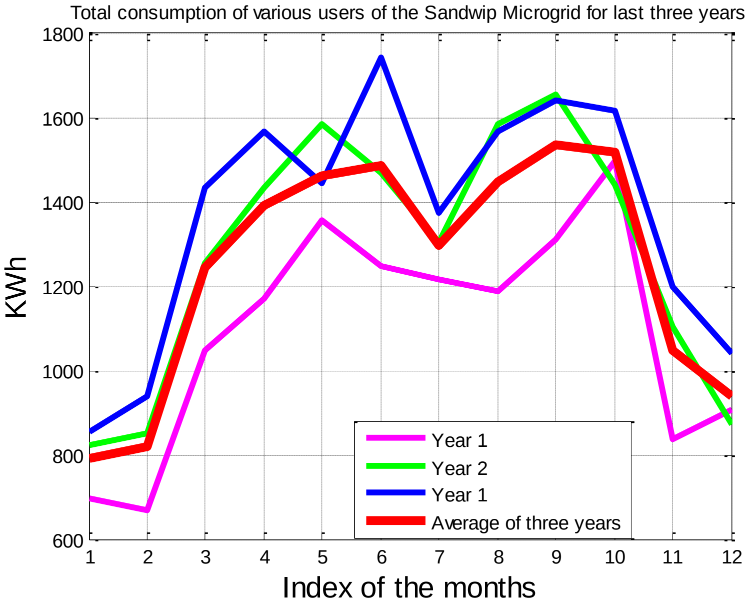


Figure 4.20: The total and average consumption of those users for the last three years (2011~2013).

Figure 4.21 shows the average consumption of the users for the last three years (2011, 2012 and 2013) as a separate figure for a clearer view.

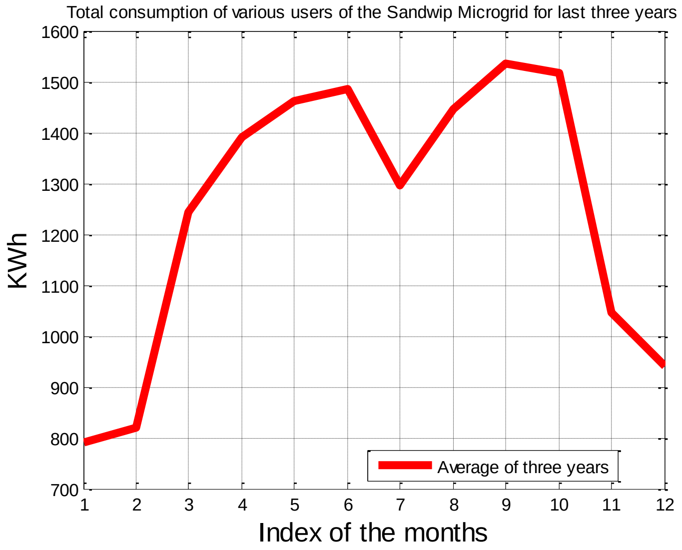


Figure 4.21: The average consumption of those users for the last three years (2011~2013).

This figure shows the approximate demand profile of 9 users of Sandwip microgrid. The actual demand profile is thus expected to be similar to Figure 4.21. Therefore, the actual demand of the microgrid will be a scaled-up version of Figure 4.21.

For avoiding complexity, the demand profile scaled up in such a way that it will have similar scale of figure 4.10 of previous analysis- around 6500KWh of consumption per month. As the scale of demand profile is similar to the previous analysis, the scale of the generation profile thus, would be similar to that of the previous analysis. 50KW$_p$ of Solar PV panel is being considered at this analysis like the previous one. The output of the panel at Sandwip for the default tilt is shown in Figure 4.22 as well as the demand profile. Figure 4.22 shows the scaled up representation of the average consumption of the users for the last three years (2011, 2012 and 2013) have a closer range of demand pattern like that of the national demand analysis.

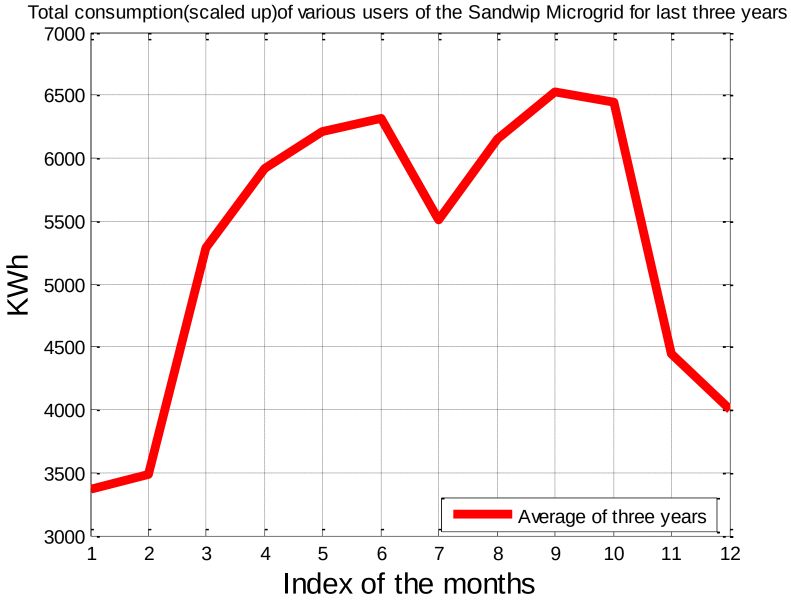


Figure 4.22: The scaled up representation of Figure 4.21.

The default tilt, optimum tilt, maximum generation of energy, maximum utilization of energy, random variation and the relationships among these have been discussed at the previous analysis. In the analysis of Sandwip, only the results are shown here. Figure 4.23 to Figure 4.28 show the results when the random variation is 0.01%, 0.1% , 1%, 2%, 5% and 10% respectively.

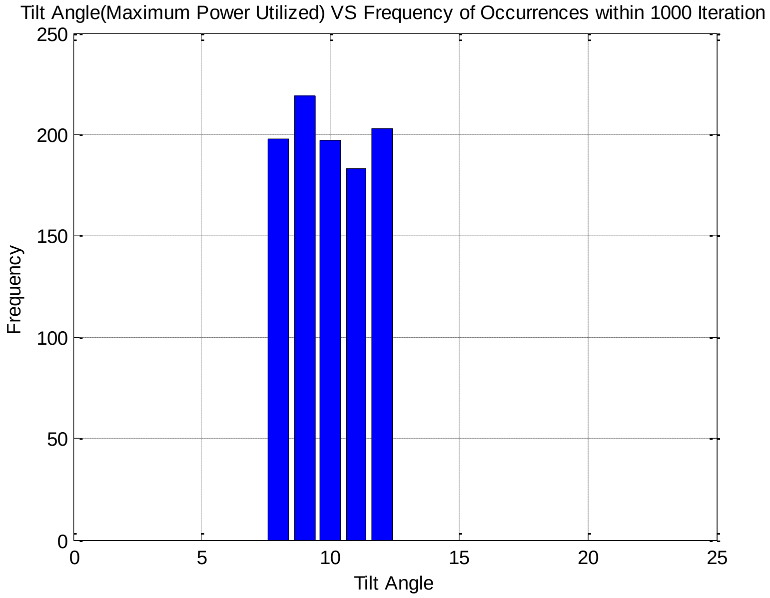


Figure 4.23: The number of maximum occurrence of minimum shortage for r=0.01% (tilt angle vs frequency of occurrences).

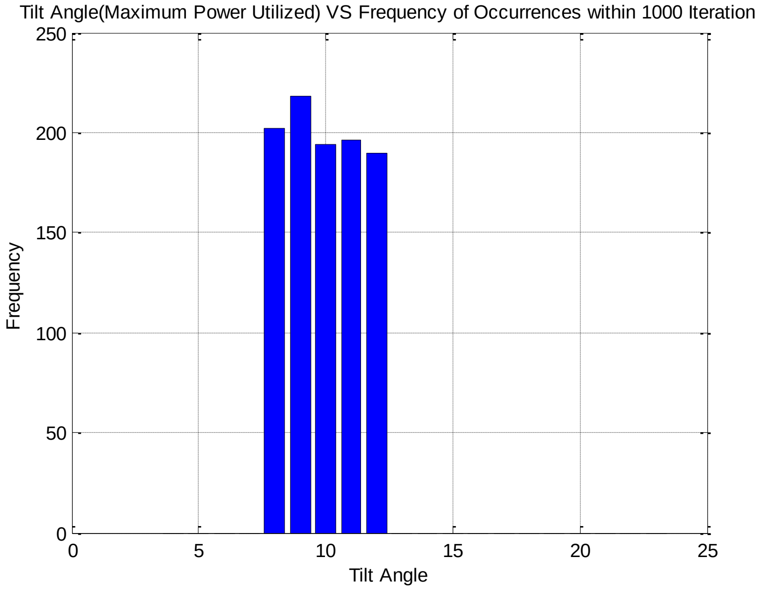


Figure 4.24 : The number of maximum occurrence of minimum shortage for r=0.1% (tilt angle vs frequency of occurrences).

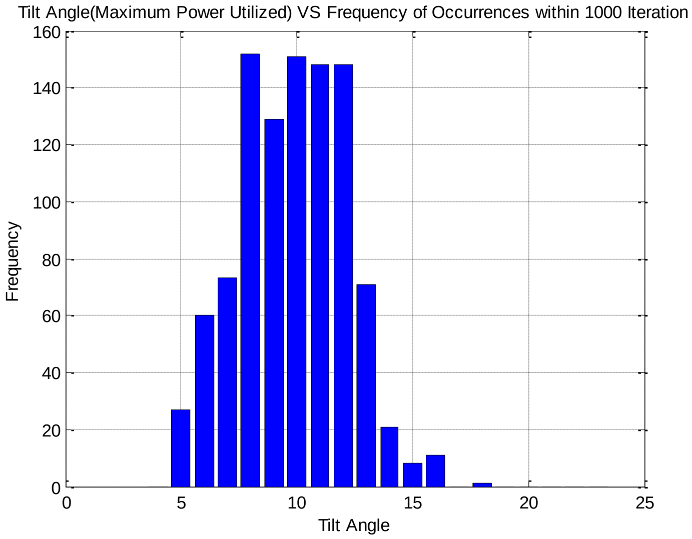


Figure 4.25: The number of maximum occurrence of minimum shortage for r=1% (tilt angle vs Frequency of occurrences).

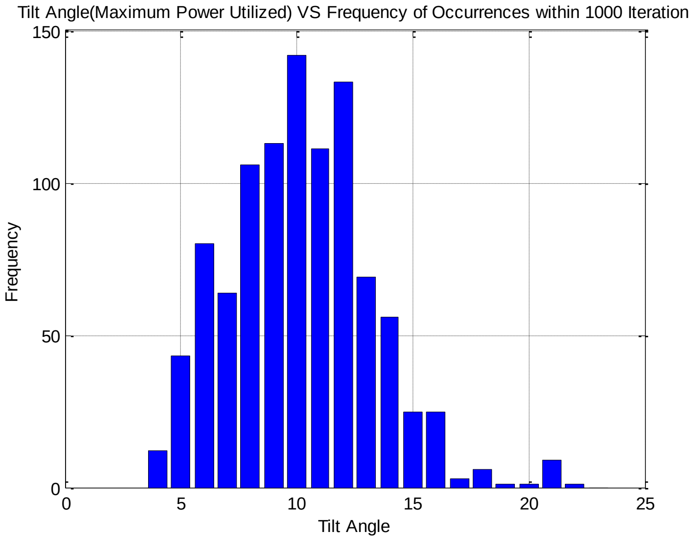


Figure 4.26: The number of maximum occurrence of minimum shortage for r=2% (tilt angle vs Frequency of occurrences).

For 0.01%, 0.1%, 1% and 2% of the random variation, in most of the cases, the minimum shortage occurance appears at the tilt angle of 8^0 to 12^0 .

For larger variation of the demand and generation such as for r=5% and 10% the number of maximum occurance is still found to be around 7^0 and 13^0. These are shown in Figure 4.27 and Figure 4.28.

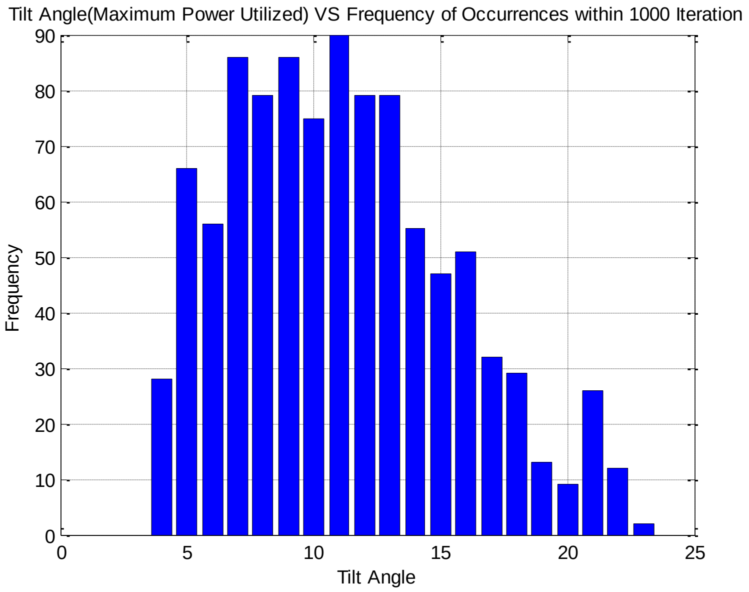


Figure 4.27 : The number of maximum occurrence of minimum shortage for r=5% (tilt angle vs Frequency of occurrences).

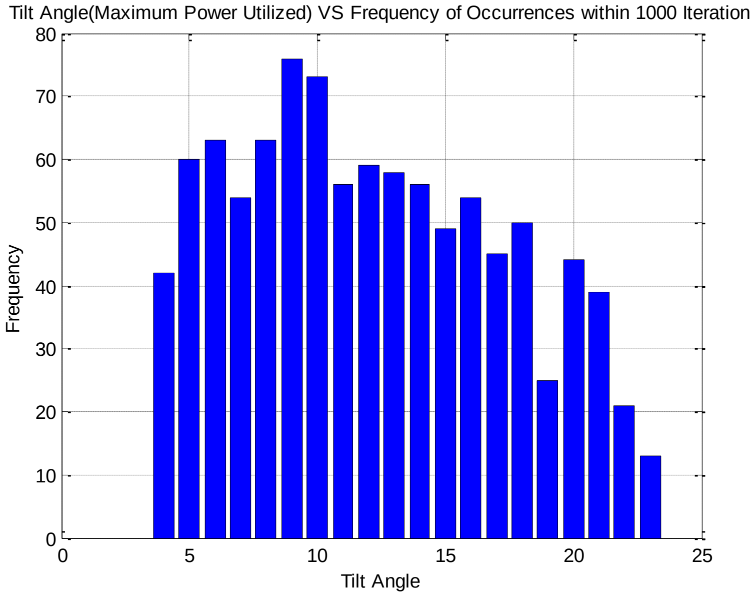


Figure 4.28: The number of maximum occurrence of minimum shortage for r=10% (tilt angle vs Frequency of occurrences).

From the above analysis, it can be deduced that utilization of maximum power for a region may not be generated at a tilt angle of the default latitude. The default latitude will produce the maximum energy over the year, but maximum utilization of power will depend on tilt angle as well as the demand profile over the year. For a demand profile of microgrid in Sandwip and generation profile of Sandwip, the minimum shortage occurs for most of the time is at a tilt angle of 9^0 and around it. The demand, generation and surplus/shortage for default tilt (23^0) and optimum tilt (9^0) angles are shown in Figure 4.29.

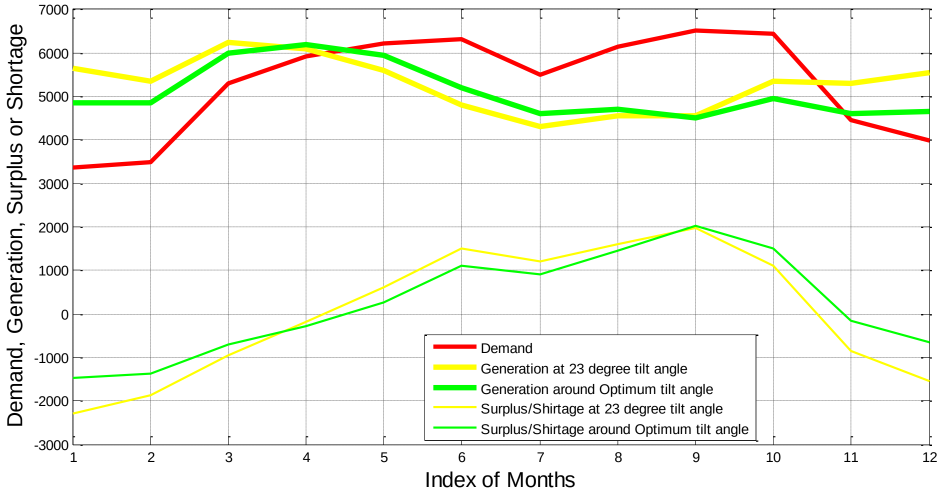


Figure 4.29: The demand, generation and surplus/shortage for 23^0 and 9^0 tilt angle.

Though the difference in output is not significant in percentage between the default tilt angle and optimum tilt angle, the amount will be larger for a larger system. It is however be noted that the change of tilt angle will not maximize the output of the PV panel, rather, it will minimize the shortage and maximize the demand met.

4.12 Summary

For a country like Bangladesh, appropriate use of renewable energy resources is very important. To have a better life there is no alternative to providing sufficient electricity to all class of the population. Renewable energy, especially solar PV, is getting popular to mitigate the energy crisis of many countries. Mini grid or microgrid concurrent with SHSs can be much more effective and may be considered as a better solution to have power with quality, reliability and sustainability. In the next chapter, a novel algorithm has been proposed for optimization of the available distributed energy resources.

CHAPTER 5

THE PROPOSED MODEL FOR DER BASED MICROGRID AND ITS IMPLEMENTATION

The last chapter described the analysis and optimization of the tilt angle of solar PV panel for a specific region. A comprehensive modeling of power generation in Bangladesh incorporating the available renewable energy resources, load demand profile and shortage/ surplus for various zones of Bangladesh has not been carried out in the past. As part of the current research, various relevant field data have been collected and appropriate mathematical models have been developed. This includes the analysis of electricity demand and its generation and optimization of the available resources, which are discussed in this chapter.

5.1 Analysis of Electricity Demand

The analysis of demand includes the yearly demand, seasonal variation of the demand and random variation of demand from the normal or average one. From the analyzed data of (sources: PGCB; last three years) it is found that the load profile follows almost a definite pattern. During the months from November to February of the year, the consumption of electricity is lower and the highest electricity consumption occurs at the month of July. Considering a number of 100 typical families of a village, the predicted/ average/ demand has been shown in Figure 5.1. In this prediction, it has been assumed that the load pattern follows that of the national grid, However, for a different load pattern, the analysis would be different.

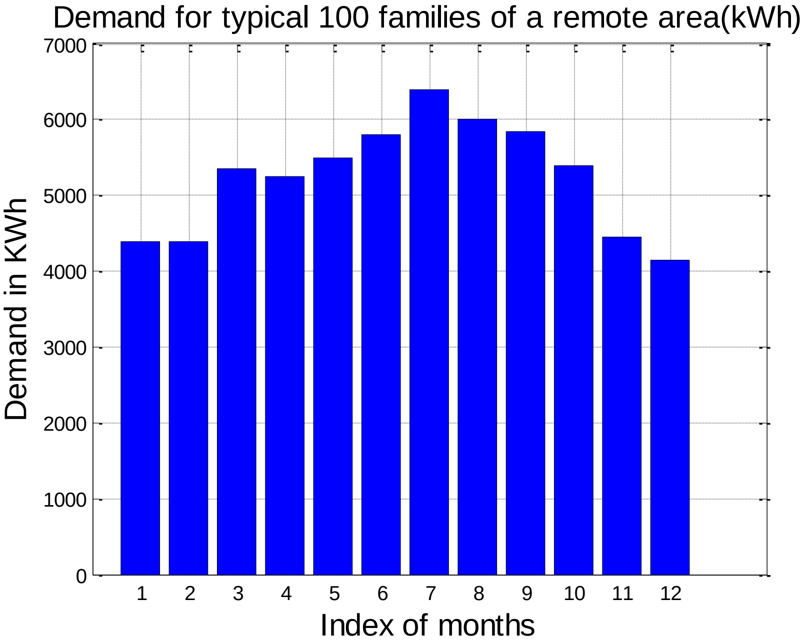


Figure 5.1: Monthly predicted average demand for 100 number of typical village family.

Figure 5.2 shows the demand and generation of the electricity for various sizes of solar PV panels and the corresponding shortage and surplus for the generation. It should be noted here that the shortage is decreasing with the increase of installed PV panels. However, reducing the shortage by installing higher energy resources is not a wise task. Hence, there should be an optimum size, where the surplus and shortage both would be minimum.

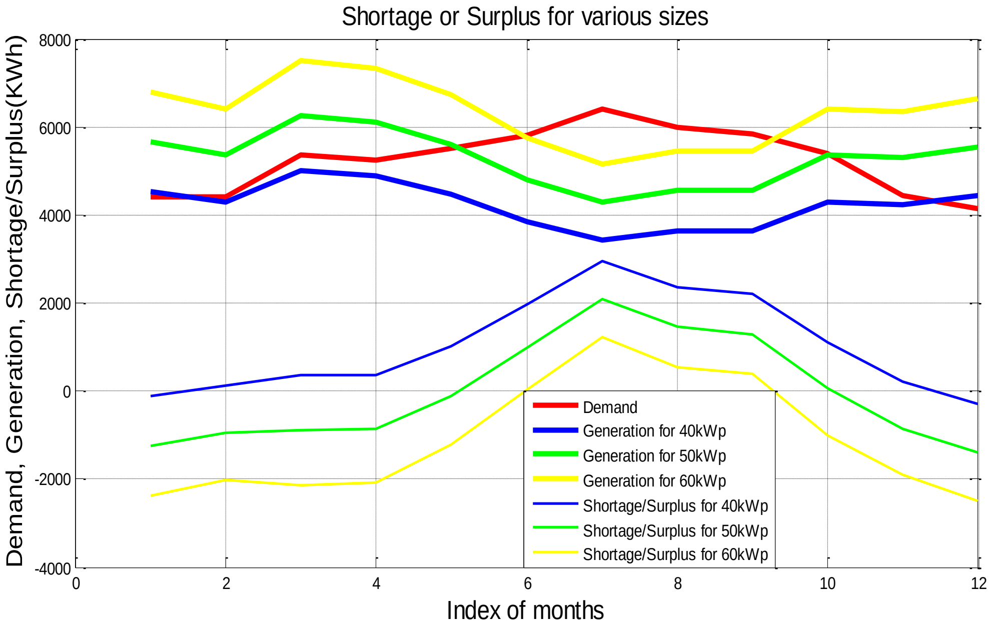


Figure 5.2: Demand, generation, shortage/surplus for various sizes of PV panels.

5.2 Analysis of the Generation

Like the demand of electricity, the generation of electricity also varies over the year depending on the availability of the energy resources. The renewable energy resources are intermittent sources. Thus, it renders long-term variation (seasonal) as well as short term (within a day) variation in its availability. Whatever be the resource- solar, wind, tidal or hydro, the generations of all individual resources vary with time. However, the resources have average generation capacity over the year. These renewable energy resources may be used to provide the power for the local inhabitants.

5.3 The Proposed Model for the DER Based Microgrid

The available microgrids are mainly a miniature of the traditional power system. That is, the electricity demand of an isolated area is supplied from a single centralized unit. In this model, single centralized generation unit is segmented as multiple smaller generation units of several renewable energy resources.

In the current research, it has been identified that proper sizing for the generation units to meet the demand is an important factor. It should be remembered that the pattern of yearly generation may not be same as the demand pattern. Shortage occurs when the demand is higher than the generation and surplus occurs when the generation is higher than the demand. Combination of several renewable energy resources with different characteristics may help a particular power generation project to match the generation pattern with the demand pattern. To have an optimum model for a distributed energy based microgrid, the following major criteria have been considered to obtain the optimum result.

(i) Minimum shortage as well as unused energy(surplus)
(ii) Maximum demand met
(iii) Minimum cost of the alternative sources
(iv) Lower cost of energy
(v) Higher penetration of renewable energy
(vi) Lower installation cost
(vii) Lower running cost

5.3.1 Modelling of electricity demand and generation

As Bangladesh has several types of renewable energy resources that have already been discussed, analysis of combination of multiple resources to properly fulfill the demand is very important. To this end in view, an investigation has been carried out to formulate an appropriate mathematical model. Finally, the following important criteria/aspects have been adopted in developing and implementing the model:

(i) Determination of the probable demand/load pattern over the year
(ii) Determination of per unit generation for each of the resources considered.
(iii) Determination of the total generation for several combinations of multiple resources with multiple numbers of units.
(iv) Determination of the generation pattern for the combined resources.
(v) Determination of surplus or shortage over the year.
(vi) Searching the minimum shortage, where the demand met is maximum and the price of alternative energy resources (such as fuel-based generator) to meet the shortage is minimum.
(vii) Determination of the combination, where the cost of energy is minimum.
(viii) Determination of the combination, where the penetration of renewable energy is the highest.
(ix) For an analysis closer to the real scenario, a random variation to the monthly/daily demand and generation has to be considered.

It should be noted here that the analysis may be of two types: simple analysis and analysis that includes random variation in demand and generation.

(a) Simple Analysis

Here, demand is denoted by D. Monthly Demand over the year is D1, D2, … … … … … …, D12 (load profile). Similarly generation is denoted by G and monthly total generation over the year is G1, G2, … … … … … G12 (generation profile). Shortage will occur for D>G and surplus when D<G surplus.

(b) Analysis Including the Random Variation

In this analysis it has been assumed that both demand and generation vary randomly for various real time causes. The demand is assumed to vary between +r% to –r% and average demands for several months are D1a, D2a, D3a, … … … D12a, where „D‟ stands for demand, the number after D is the index of the months and „a‟ stand for average. The daily demand of a month can be predicted from the average monthly demand including the random variation in it. This is shown in equations 5.1 and 5.2.

For January (D1):

The number inside “( )” after Dn represents the particular day of the month.

$$D1(1) = D1a*[(100-r)+ 2*r*rand()]\% \ldots \ldots \ldots \ldots \ldots \ldots (5.1.1)$$

$$D1(2) = D1a*[(100-r)+ 2*r*rand()]\% \ldots \ldots \ldots \ldots \ldots \ldots (5.1.2)$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot$$

$$D1(31) = D1a*[(100-r)+ 2*r*rand()]\% \ldots \ldots \ldots \ldots \ldots \ldots (5.1.31)$$

A generalized formula can be expressed as

$$Dn(x) = Dna*[(100-r)+ 2*r*rand()]\% \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5.2)$$

Similarly, the prediction of generation for a resource may be expresses as

$$Gn(x) = Gna*[(100-r)+ 2*r*rand()]\% \ldots \ldots \ldots \ldots \ldots \ldots \ldots (5.3)$$

where,
„n‟ denotes the index of a month
„x‟ denotes the x^{th} day of a month
„a‟ indicates the average
„r‟ is the probable variation of demand or generation
„$rand()$‟ produces a random value that is greater than 0 and less than 1.

As, there are several types of energy resources, the total generation will be the summation of all the generations as follows:

$$G_T n(x) = G_1 n(x) + G_2 n(x) + \text{-------------} + G_m n(x) \ldots \ldots \ldots \ldots \ldots (5.4)$$

where,
$G_T n(x)$ = daily total generation by all of the resources for month of n
$G_1 n(x)$ = daily generation by resources 1 for month of n
$G_2 n(x)$ = daily generation by resources 2 for month of n
$G_m n(x)$ = daily generation by resources m for month of n

Thus, the demand and generation for each individual day can be randomly predicted using equations (5.2) and (5.3). This will provide closer view of a realistic demand and generation scenario. However, variation of demand and generation could also be predicted in a similar way on top of the monthly data (Figure 5.1 and Figure 5.2) easily, which would provide a crude approximation of the variation, but has not been used here.

It is expected and logical that the combination of several types of renewable energy resources will best fit the generation profile with the demand profile. The calculation of the analysis has been incorporated using the MATLAB programming environment. The MATLAB implementation routine is included in Appendix-D.

5.4 Optimization of the Resources

There may be multiple numbers of resources. This model is a general model in which combination of several types of resources could be analyzed. Considering N_1 number of size for resource R_1, N_2 number of size for resource R_2, and N_m number of size for resource R_m will have N_{total} number of different combination of resources.

Where,

$$N_{total} = N_1 \times N_2 \times N_3 \ldots \ldots \ldots \times N_m \text{ --- --- --- --- --- } (5.5)$$

The analysis has been done based on this idea. Due to the enormous size of combinations and thus a huge amount of data to be handled, the analysis of only a single resource has been discussed in this chapter.

An optimized design does not necessarily provide a unique result. The basis of optimization is an important factor, such as optimization for minimum production cost per unit, minimum installation cost, maximum penetration of renewable energy, minimum cost for alternative energy resources, etc. Change in the basis of optimization will change the result. An optimum design for minimum shortage does not mean the optimum design for minimum production cost or so. Among the several types of optimization, Figure 5.3 shows the result for optimum size of PV panel that has to be installed for minimum shortage and minimum surplus.

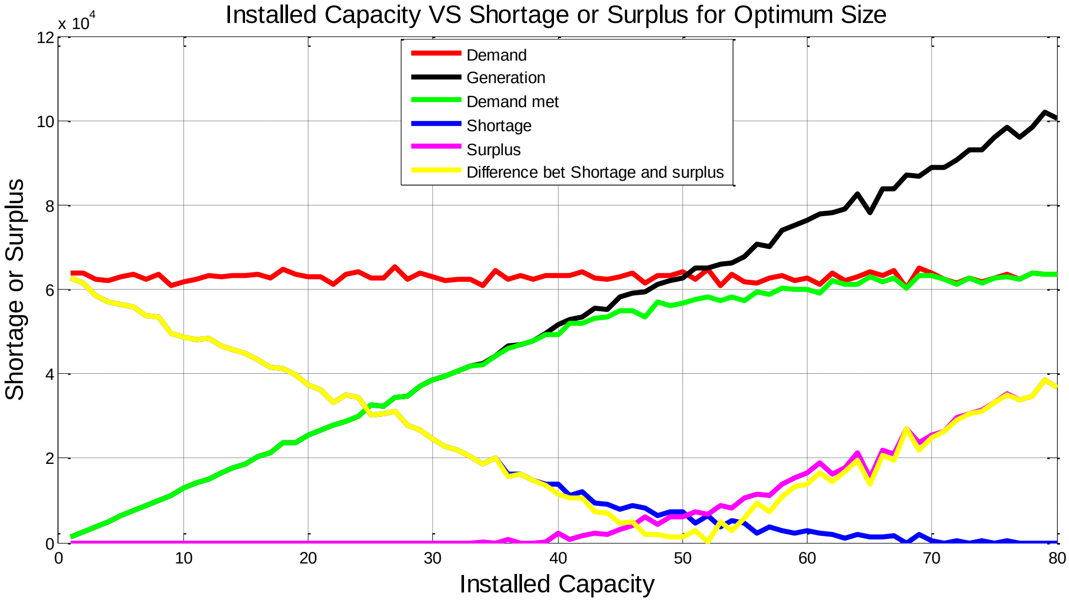


Figure 5.3: The optimum scale of the solar PV for minimum shortage and minimum surplus.

To design the project properly, the following criteria should be taken into consideration:

(i) Utilization of the surplus
(ii) Back up for the shortage
(iii) Maximize the penetration of renewable energy
(iv) Ensure the minimum cost of energy
(v) Minimum utilization of the fuel-based generator
(vi) Minimum shortage
(vii) Minimum surplus
(viii) Minimize the unused energy
(ix) Cost of the fuel based energy to meet the shortage.
(x) If the surplus is kept zero that is all energy generated is consumed then the shortage will be maximum thus the cost of extra energy will be maximum.
(xi) If the shortage is to be zero, surplus will be maximum and the installation cost will be higher.

An optimization algorithm has been formulated where the above criteria have been taken into consideration. This algorithm has been implemented using MATLAB programming environment and included in Appendix-D. The results of the analysis of demand and generation as well as the optimization algorithm will be discussed in chapter 7.

To show how the model works, only one energy resource (solar PV alone) has been considered to obtain the output in this chapter. However, solar, biogas, wind, diesel hybrid system has also been analyzed in the same way and the MATLAB program is included in appendix-D. The results of this analysis is shown in Appendix-E

5.5 Summary

The proposed model for the analyses of demand and generation and the algorithm for optimum use of the available distributed energy resources have been discussed in this chapter. In the next chapter, a realistic and reliable design model for optimum utilization of the DER based microgrid will be presented.

CHAPTER 6

CONSUMER IS PRODUCER - A NOVEL MODEL FOR ELECTRICITY GENERATION

Chapter five described the proposed algorithm to optimize the available distributed energy resources. This chapter explores a new model to generate electricity with higher penetration rate of renewable energy. Conventional system to generate electricity is to generate large amount electricity and it reaches to the consumer through a long transmission line and distribution system. The losses and costs, incorporated with these processes, are not negligible. Another System is the Solar Home System (SHS), which has been used in Bangladesh from 1998 to replace the traditional kerosene based lamp and enable the use of battery based TV, DC fans and light bulbs. With the advancement of technology, the energy demand of the consumers is increasing significantly. To meet this demand, it needs connectivity to the national grid. An alternative to this is to produce enough power at the consuming spot. A novel method to achieve this has been discussed in this chapter. A brief overview of the power sector of Bangladesh and some of the topics discussed in the previous chapters have been repeated here for convenience. Also, the performance of the proposed system has been compared with that of the traditional power system.

6.1 A Short Overview of the Power Sector of Bangladesh

Bangladesh is a small country with a large population and the generation of electricity is not enough to serve the population. Presently, 62% [1] of the total population (including renewable energy) has access to electricity and per capita generation is 321 kWh, which is very low compared to other developing countries. Along with the centralized generation, till April 2014, about 3 million SHSs have already been installed in the off-grid rural areas of Bangladesh under the program run by IDCOL with co-operation of several other supporting agencies. As a result, more than 13 million beneficiaries are getting solar electricity, which is around 10% of the total population of Bangladesh. Most of the installed units of SHS are used at homes. A few of them are used in educational institutes, prayer houses and shops in the market. A solar home system is able to provide electricity for a few light bulbs, small DC fan and TV, rechargeable torch light, adapter for mobile phone charging etc.

However, the energy demand of the customer is increasing significantly. Many of the customers have intention to use a large TV, fridge, electric iron, blender, domestic water pump even AC, like a customer having connection of national grid electricity. However, extension of the grid is not an easy task. Besides this, most of the power stations is based on natural gas which is about 78.12% of the total capacity on the FY 2013 [1]. On the other hand, natural gas is on short supply and about 1500 MW of generation shortfall occurs due to shortage of gas [15]. Therefore, it will be very tough to provide more electricity generated from the natural gas in future. Government of Bangladesh is trying for some alternative of natural gas such as coal, HSD, Furnace oil based power plant as the fuel diversification program [1][2]. Presently, use of gas, HSD, Coal and FO are around 80%, 10%, 5%, 3% respectively [15] of the total generation. On the other hand, Bangladesh naturally receives plenty of solar radiation from the sun. Wind, mini hydro and micro hydro are also available and there is scope to solve the problem of electricity generation with the combination of several renewable energy resources with storage and non-renewable fuel-based generation units.

6.2 Field Survey

A field study has been carried out on several customers of the existing SHSs including the area of Jessore, Rangpur, Laksmipur, Mymensingh, Sandwip, Hatia and Vola from November 2012 to August 2014. It is found that many of the remote areas are yet far from the national grid. In those areas, most of the inhabitants use kerosene lamps/lanterns for lighting purposes. Some of them are using diesel or petrol-based electrical generators in groups for a limited period of the day due to higher fuel cost. SHS is also being used in this area. SHS system is primarily design for lighting purposes. It can also provide energy to TV and low power DC fans. The users of current SHS are interested to use standard TV, fridge, fan, small water pump etc. However, due to lack of enough power, they cannot use these appliances. An alternative way to meet their demand and to provide the similar service as the national grid does, is to produce enough power at the consuming spot and interconnect them locally. This study also shows that a typical house at a village area (nearest to an electrified village) consumes about 50 kWh of electrical energy per month. The average free space of roof is about 40-50 m^2 and the average usable space for solar PV application is about 18-25 m^2 whether the roof is South (or North) faced or East (or West) faced for a slopped rooftop. For a flat roof, the complete roof area may be used. This area is enough to install solar PV of more than 2-3kW_p capacity. It will produce about 210-450 kWh of usable electricity per month, which is enough for 3-5 families of a village, considering the consumption pattern of a traditional family.

6.3 Scopes of Interconnected Microgrids

A conventional power system usually consists of large scale power stations, transmission lines, substations and distribution lines etc., where the generation and consumption of power are not at the same location. By this system, remote areas are normally not connected with the electricity grid, and thus are deprived from development to take place. The traditional power system is also associated with transmission and distribution losses, environment pollution, higher installation cost as well as running cost. Moreover, the load management system also hampers a large number of users. Using the available resources in a remote area, the output of each source of energy i.e. solar PV, biogas, wind etc. may be interconnected locally, and thus this interconnected system will provide enough electrical energy for the entire user of the locality by means of Micro-grid [7]-[9]. The idea of microgrid and DER is being used in several countries in a larger scale. The penetration of DER based microgrid is increasing in the developing country day by day. A Revolution of the microgrid can solve the power crisis of the world in an easier way.

Considering the points above, a new model for generation and distribution of electricity has been proposed. It is expected that the implementation of this model will ensure less transmission and distribution loss and the cost will also be minimized significantly, emission of CO_2 will be negligible with a new load management technique as well as ensuring reliable and quality power within the shortest possible time.

6.4 Consumer is Producer - an Alternative Approach

[1]

[2] Consumer is Producer (CP) model is a new technique to generate and distribute electricity with higher power quality, stability, reliability, lower transmission and distribution loss and the overall lower cost to produce electricity. It is designed as easier as plug and play equipment. It will be able to provide electricity to a large number of populations within the shortest possible time.

[3]

Before discussing the model, the topology of several layers of the model of the microgird should be clarified at first. In this context, Figure 3.7 and Figure 3.9 are recalling here.

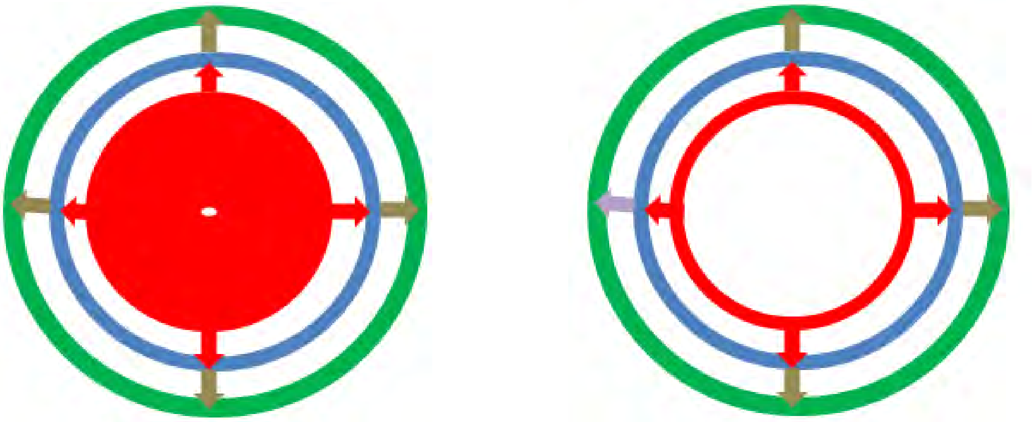


Figure 6.1: Recalling Figure 3.7 and Figure 3.9.

Figure 3.7 is the traditional microgrid, where there is no transmission line, rather user level distribution is present only and the generation of power is centralized and Figure 3.9 is the proposed microgrid, which is similar to the traditional microgrid but power generation is distributed over the entire area.

Generation is shown by red rings, blue rings represent the low voltage level distribution and the green rings represent the consumers. To show the generation and the consumption at the same place, the red and the green rings are merged by both of the colors. This is shown in Figure 6.2.

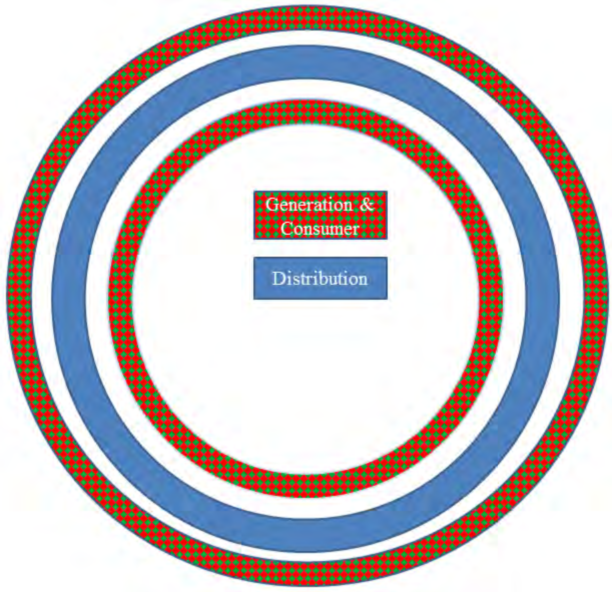


Figure 6.2: Ring diagram of a new microgrid model, where the generation and consumption will take place at the same point.

In the proposed model, generation and consumption will take place at same point. And the distribution line will be used to share the power to several users as well as proper management of the microgrid. Thus the layers of the microgrid may be expressed by Figure 6.3.

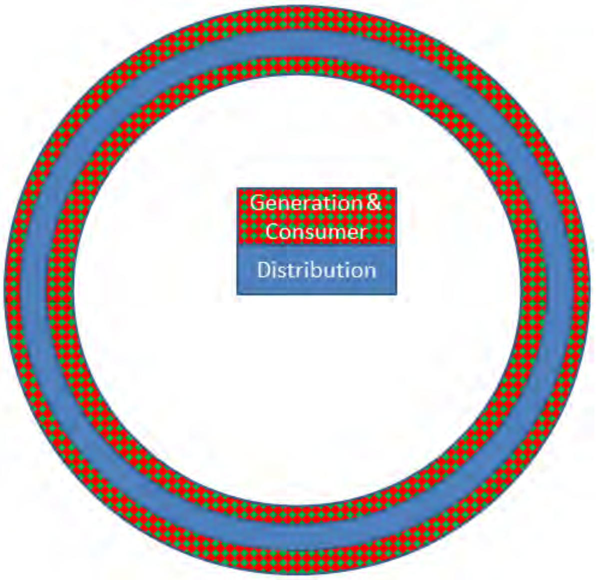


Figure 6.3: Several layers of the proposed microgrid, where closeness of the rings shows the integrity of generation and consumption.

Instead of using two different rings for showing the generation and consumption, single ring has been used to express the idea in Figure 6.4. As the name implies, this ring may be called the layer for consumer-producer units.

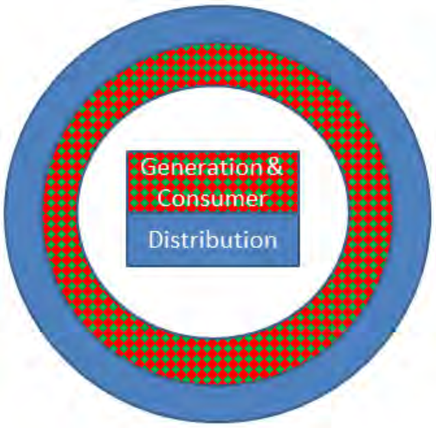


Figure 6.4: Two different rings expressing the consumer and producer units have been merged into a single ring keeping the distribution close to the generation and consumption**.**

This type of microgrid may form in several places of remote areas of a country. In this case, interconnection among the microgrids will be possible. Development of microgrids in several places is shown in Figure 6.5.

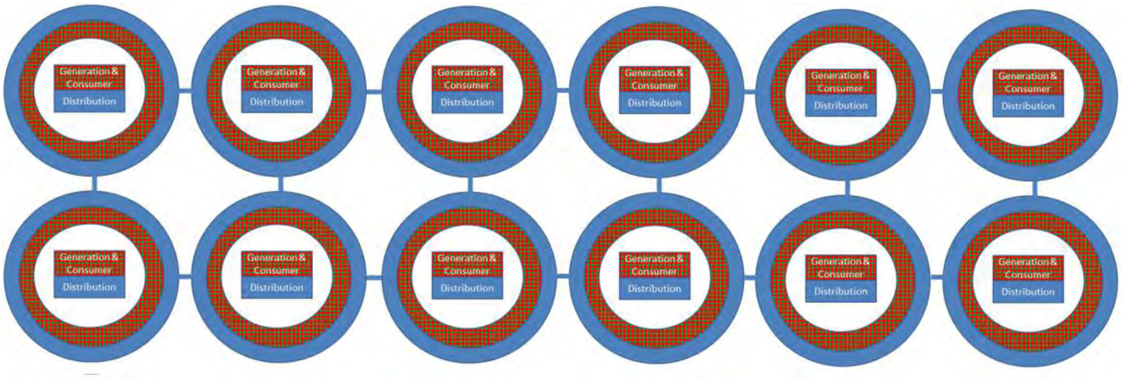


Figure 6.5: Discretely developed microgrids, may be interconnected.

[4] So far, the topology of the proposed microgrid has been discussed. The layers of the model comprises with Consumer Producer Unit (CPU), microgrid, interconnected microgrid, and control and management unit. Brief descriptions of these are given below.

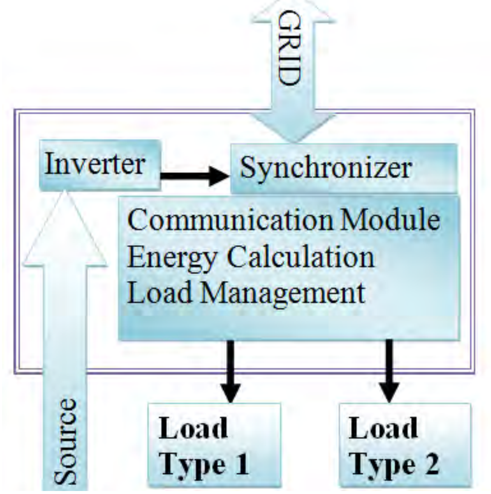
[5]

6.4.1 CPU

[6]

[7] The unit CPU (Figure 6.6) consists of source or sources, loads, control and management system in a unit. Each CPU has its unique identification number.

[8]



[9]

Figure 6.6: Block diagram of Consumer Producer Unit (CPU).

[10]

[11] ***Sources:*** The sources may be solar PV, biogas based-generator, small wind generator, small hydro power generator, fuel cell, micro-turbine, gas or diesel generator or any storage element such as battery, fly wheel etc.

[12]

[13] ***Inverter:*** Whatever be the output of the sources is, the output of the inverter will be AC. Inverter output is kept same as that of the grid.

[14]

[15] ***Synchronizer:*** The task of the synchronizer is to synchronize the output of the inverter with another CPU or with the grid.

[16]

[17] ***Communication module:*** The task of this module is to communicate with a Master controller or central controller about the status of the CPU. It receives command from the central controller and executes the command such as to disconnect any load, disconnect itself or disconnect sources (for example, diesel generator was running over the night and at the day time central controller accumulates the data of all of the CPU and decides that, now there is no need to run the diesel generator, then it will send command to the CPU of the diesel generator to stop it.)

[18]

[19] ***Energy meter:*** It measures the amount of generated or consumed energy; calculate the bills for peak time, off peak time, demand charges etc. Energy calculation module calculates the energy incoming from the grid, outgoing to the grid and the amount of energy used by the loads.

[20]

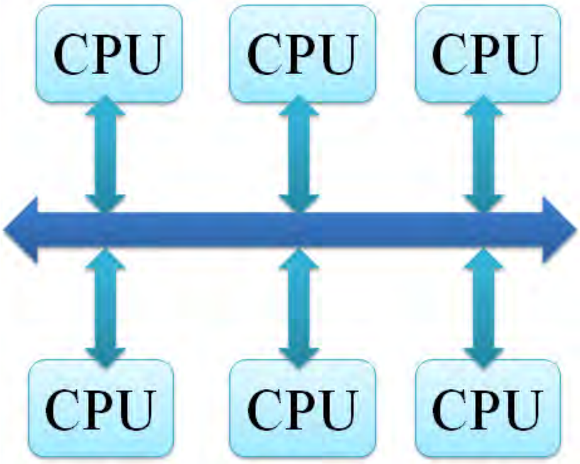
[21] ***Loads****:* The loads of the consumer is categorized for a better load management, such as lighting load, fan load, refrigerator, TV, computer, and heavy loads like AC, pump etc.

[22]

6.4.2 Microgrid

[23]

[24] The microgrid is an inter connection of several numbers of CPUs. The formation of a microgrid by several CPUs is shown in Figure 6.7. This is an alternate expression of Figure 6.4

[25] 

[26]

[27] Figure 6.7: CPU based Microgrid.

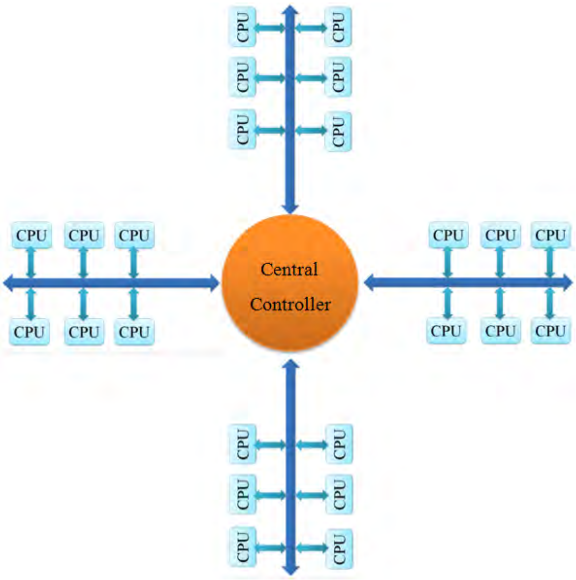
[28]

6.4.3 Interconnected Microgrid

[29]

[30] Interconnection of several microgrids may be achieved by using central controller as shown in Figure 6.8. This is an alternate expression of Figure 6.5. However, interconnections of microgirds have not been shown in Figure 6.5.

[31]

[32] 

[33]

[34] Figure 6.8: Interconnection of Microgrid with central controller.

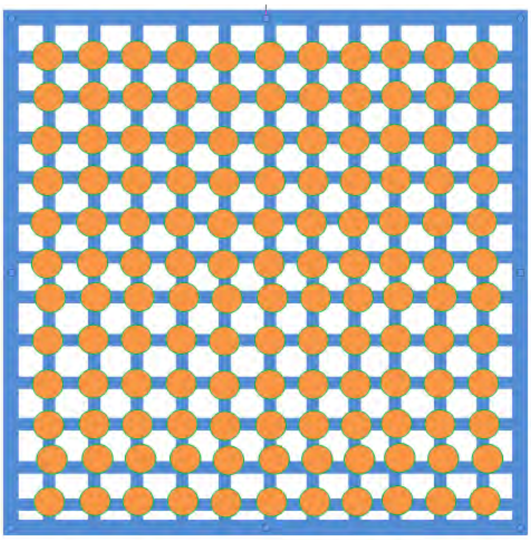
[35]

6.4.4 Microgrid Network

[36]

[37] When a large number of interconnected microgrids are combined together, it will form a microgrid network. The microgrid network may be considered as a unit power source that will be connected to the nearest transmission and distribution lines. This is shown in Figure 6.9.

[38]



[39]

[40] Figure 6.9: Microgrid Network.

[41]

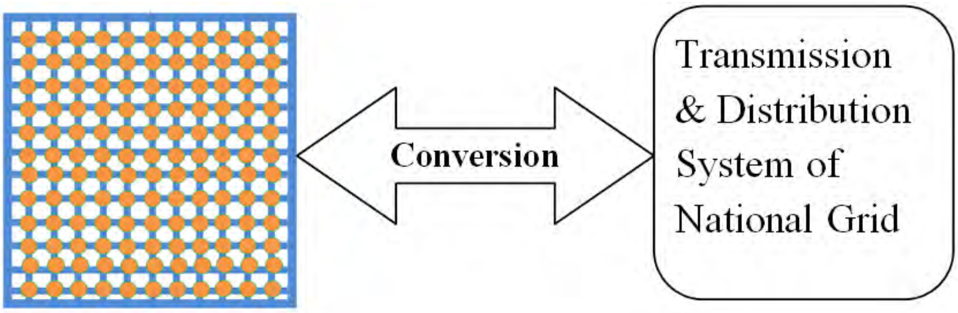
6.4.5 Connection to national grid

[42]

[43] An option has been provisioned for it to be connected to the nearest national grid when available. Through this connection, it is possible to transfer power to the grid on demand. This is shown in Figure 6.10.

[44]

[45]



[46]

[47] Figure 6.10: Microgrid connected to national grid.

[48]

6.5 Control and Load Management

[49]

[50] The control of voltage, frequency, real and reactive power, droop[4] etc. can be controlled by the central controller of the interconnected microgrid. It will control the frequency, voltage and other parameters to ensure better quality of power. Like the central controller, each of the CPU has its own identification number. Each central controller will be connected to some branches of a microgrid, but it will control only a few of the branches which are defined to be controlled under it. As the loads are categorized, the central controller will send command to disconnect some types of load when generation is less than the demand. Under this circumstance, the traditional method is to disconnect the branch completely, and as a result, a large number of consumers are affected.

---

[4] Sloop of frequency vs power

[51]

6.6 Determination of Maximum Voltage Between Two Isolated Microgrids when Interconnected

The energy resources are distributed (Figure 6.7) over the microgrid (proposed) instead of central power generation. For such a system, the loads and the resources may be expressed by the thevenin equivalent circuit. Figure 6.11 is expressing the thevenin diagram of an isolated microgrid.

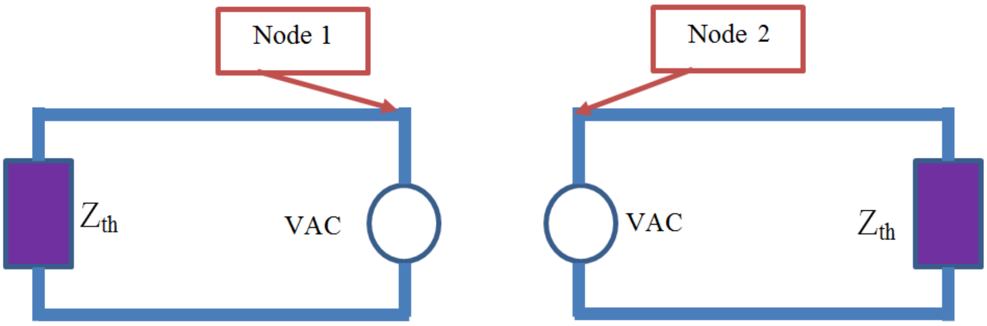


Figure 6.11: Two CPU based isolated microgrid are expressed by equivalent thevenin circuit.

The interconnection of these two microgrid may be done by connecting node 1 and node 2. This connection is used for transferring power from one microgrid to another. Thus the characteristics/parameters of this line could be found out through a similar as that of transmission line. This line may be expressed as by Figure 6.12 and Figure 6.13 with a combination of an equivalent resistance, inductance and capacitance [29].

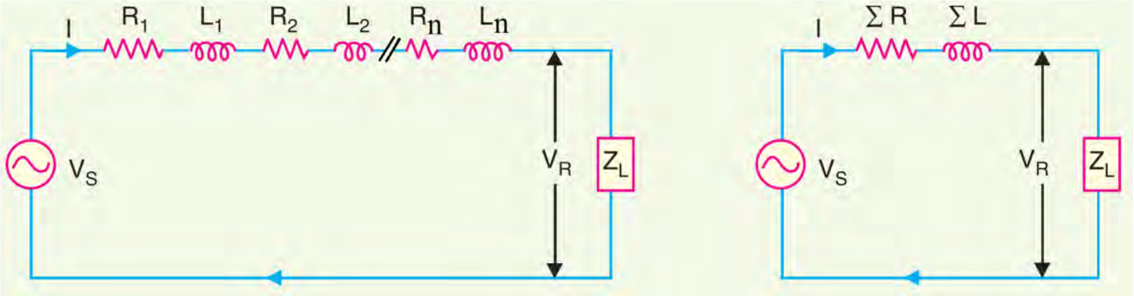


Figure 6.12: Resistance, Inductance and capacitance of the line and equivalent.

Here, R_1, R_2… R_n denotes the resistance of the various segments of the line and L_1, L_2… L_n denotes the inductance of the various segments of the line.

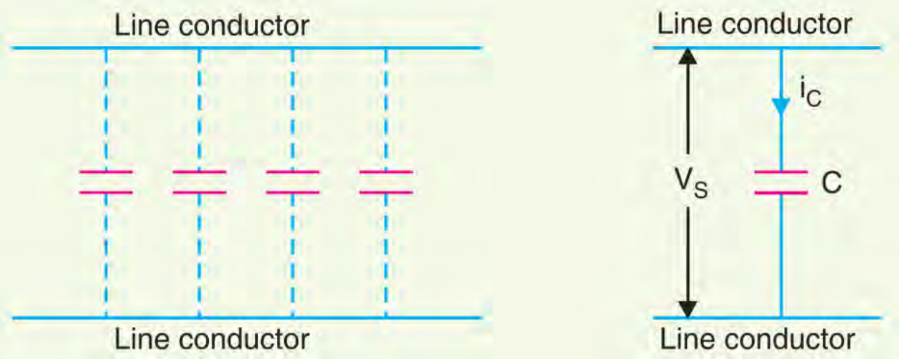


Figure 6.13: Capacitance of the line and its equivalent.

There will be a voltage drop between the nodes only if there is any current flow through the line and thus power transfer. In such a case one node will deliver power to the other node. Therefore, one node could be assumed as a source and another could be as load. The complete equivalent circuit may be expressed by a combination of equivalent source, resistance, inductance, capacitance and load [29]. This is shown in Figure 6.14

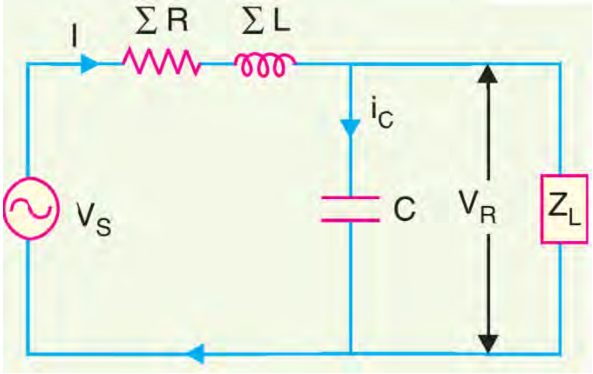


Figure 6.14: Equivalent circuit of the inter-connection line.

The parameters could be found by analyzing the characteristics of the conductors. The inter-connection line is nothing but a low voltage level distribution line. Typical distribution line characteristics [29] are given below:

Conductor characteristics

Single phase Cable: *Aluminum*
Length $=1km$
Radius of the conductor$=1cm$
Distance between the conductor $= 0.5m=50cm$
Resistivity of conductor at 20^0C, $\rho = 28.2\ n\Omega\text{-}m$
Cross sectional area, $A=\pi r^2 = \pi \times 10^{-4}$

The inductance of line per m could be found by this equation
The resistance, inductance and capacitance could be found by the equations 6.1 to 6.3. However, as there are two conductors, the total resistance will be double of *R*.

Resistance of line,

$$R = \rho l/A \quad \text{……………..(6.1)}$$

Loop inductance per meter,

$$L = 10^{-7}[1 + 4\ln(\frac{d}{r})]\ H/m \quad \text{……………..(6.2)}$$

Capacitance per meter,

$$C = \frac{\varepsilon\,\pi}{\ln(\frac{d}{r})} \quad \text{…………………(6.3)}$$

Inductance and capacitance for per km of line could be found by multiplying this value by 1000. From the value of L and C, inductive reactance and capacitive reactance could be found by equations 6.4 to 6.5.

Inductive reactance,

$$X_L = 2\pi f L \text{ ………………….(6.4)}$$

Capacitive reactance

$$X_L = 1/2\pi f C \text{………………….(6.5)}$$

The microgrid is small and isolated. Assuming a total 10KW load being served in a microgrid by another, the is Standard impedance for 10KW load with power factor 0.8 This information are incorporated in a MATLAB file which is given in Appendix –F and output of program is shown in Figure 6.15. It is found that the voltage drop increases with the length of the interconnection line.

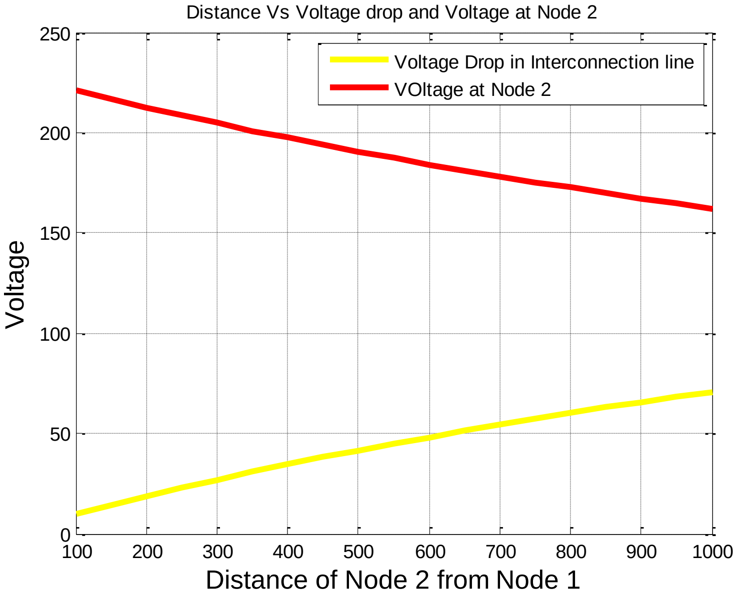


Figure 6.15: Voltage drop vs distance of interconnection.

The Figure shows that the voltage is around 210V for a distance of 300 meter. Therefore, three or more CPU may be inserted into the interconnection line to reduce the distance around 300 meters instead of 1000 meters.

6.7 An Applicable Implementation Policy

The proposed scheme is a new model and hence it needs appropriate policy to be incorporated. Policy is an important factor for any program. There may be several entities to form the proposed microgrid. The users may form a microgrid by interconnecting their own CPUs. However, this will create problem if there is no policy for interconnection in the local grid. Without any controlling entity over the grid, it will be more complicated to implement this scheme. Therefore, it is better for a new entity to be connected into an already formed microgrid.

For a better explanation of the problem, let us assume that entity 1 will provide the connectivity to the local microgrid for any new entity. Entity 1 will be responsible for the generation, grid related hardware and software support and the backup power. It will have its own power as well as buy power from entity 2. Entity 2 will be responsible for generation, backup (in some cases) and consumption. There may be a third type of entity namely, entity 3, which would be responsible for consumption only. Suppose that all of the power generated by entity 2 will now be sold to entity 1 with a price of B Tk./unit and entity 1 will sale this power to entity 2/entity 3 with a price of S Tk./unit.

As renewable energy resources are intermittent sources, there must be a backup power or storage of energy to have a reliable and continuous power supply. If anyone of entity 2 wishes to stay disconnected from the grid and have a smooth and reliable operation, he must have additional backup power and generation. Thus, it will cost 3~5 time more than the cost if connected with the grid. In this case, the return of initial capital will be delayed; actually, there will be no return, instead there will be a saving of cost of energy. Therefore, it is better to be connected with the grid, as it will reduce the initial investment and ensure the reliable and continuous supply of power.

For individual use, the day of autonomy is important. Day of autonomy is defined as the number of days in which the system will be able to operate without any interruption. It is kept as three days as standard. This is done by storing the energy into deep cycle batteries. This costs a huge portion of the initial cost. Presently, market price of $100W_p$ panel is about 6,000Tk. and the battery used to store the energy of the panel for 3 days autonomy (150Ah-12V), which costs about 18,000Tk. There are also costs for wiring, structure, controller and labor. By these ways, it will cost around 300Tk. per W_p to be installed. The market price of an SHS without inverter is about 40,0000Tk. Thus initial cost will be around 400Tk per W_p of solar panel.

In the case of grid connected mode, the cost is associated with only the panel, controller (here CPU), structure and labor. There is no cost for the storage. The approximate cost for the CPU may be 40,000Tk. for a $2KW_p$ capacity panel. Including other costs such as labors, cable etc., the total cost to install a $2KW_p$ capacity PV panel will be around 1,20,000Tk. In this way, it will cost around 90Tk. to install $1W_p$ of solar panel. However, in this mode, cost for backup energy whether it is by means of battery or fuel based generator, will solely be borne by entity 1. It is to be noticed that the backup of the power may be accomplished by using battery only or by using fuel based generator with battery. For individual use, whether the backup energy is by means of battery (3 days autonomy needs a battery of large size) or by means of battery with fuel based generator, it will make the cost higher for entity 1 whereas, the cost will be lower for the grid connected mode as it is a large system.

On the other hand, the day autonomy for a grid is not three days rather the autonomy is for the period of sun set to sun rise (actually the period of zero production to start of production by the solar panels). For this reason, the size of the battery needed for the grid connected mode is just enough to store 40% of the total energy produced by the PV panels (like Sandwip Microgrid). Moreover, additional cost will be needed for the generator to run on the fuel. As a result, the cost associated for backup power or alternative energy for the grid connected mode would be much less than that for the individual mode. However, the running cost will increase slightly. Other cost associated with entity 1 is for the poles, cables, controllers for the distribution system.

For a clear understanding, the discussion may further be divided into two stages; namely, stage 1: for building the grid backbone and a few of the power sources, which are related to entity 1, and stage 2: for interconnection of new CPUs to the existing grid, which is related to entity 2. Let us calculate the cost for a 100KW$_p$ solar microgrid (CP model) with the help of these stages.

6.7.1 Stage 1: Building the grid backbone and a few of the power sources

In this stage entity 1 will all the requirements that have already been discussed for the grid backbone so that entity 2 / entity 3 can easily connect their CPUs when they wish. Power generated by entity 1 and entity 2 will be available in the grid to be consumed. Approximate cost for the stage 1 is given the table below. It is assumed that initially demand as well as the number of connected CPUs will be less than that of saturated grid. Let, the total connected solar panel by entity 1 is SP_l and by entity 2 is SP_1. In this case, the total connected CPUs in the grid will be SP_T. Battery needed for this size of solar panel is B_T (Sandwip) whether it is served by entity 1 or by entity 2. For easy calculation, it is assumed that the total battery needed will be installed by entity 1. Also a fuel based generator is needed for a reliable operation. The size of the backup generator will depend on the maximum demand of the system.

Presently, 40 customers are connected to the grid per km of distribution line (PDB and PBS data). For 200 users (types 2 and type 3), it needs 5km distribution line and 1km for interconnections of the line. The number of distribution pole is around 60 (1 pole per 100 m). There are also cost involvements for central controllers and others equipment.

6.7.2 Stage 2: Interconnection of new CPU to the grid

It was mentioned previously that, the free space of rooftop a typical village is enough to install 2KW$_p$ of solar panel. In this case, there will be no additional cost for the land.
The associated cost is given in Table 6.1.

Table 6.1: Initial investment for entity 1

Components	Size	Price Breakdown	Total BDT
Panel	10KW$_p$	10,000*60=6,00,000	6,00,000
Battery	48000Ah, 12V [5]		48,00,000
Distribution System	5km	5km*80,000=4,00,000	4,00,000
Distribution Pole	60	60*10000	6,00,000
Diesel 10KW Generator	3	2,00,00*3	6,00,000
Control Equipment			1,00,000
Others (Land, labor, transport etc.)	10,000 per KW$_p$		1,00,000
Total			70,00,000

---

[5] Size of Battery is determined from the data of Sandwip 100KWp Microgrid

Installation cost for entity 1 may be given by

$$C_{T1}= C_P + C_B + C_{DL} + C_{DP} + C_{FG} + C_{CE} + C_o \dots \dots \dots \dots \dots (6.1)$$

where,

C_{P1}= Cost for solar panel
C_B= Cost for Battery backup
C_{DL}= Cost for Distribution lines
C_{DL}= Cost for Distribution poles
C_{FG}= Cost for fuel based generator
C_{CE}= Cost for Control equipment
C_O= Other costs (labor, land transport etc.)
C_{T1}=Total Cost.

The Per Year Calculation for Entity 1 is given in Table 6.2

Table 6.2: Per year calculation for entity 1

Item	**Notation**	**Amount in KWh**	**Unit price Tk./KWh**	**Total cost (Tk.)**
Usable energy from the Panel per year (entity 1)	E_{P1}	13,000		
Total energy buy from entity 2 (90KW$_p$) 56,00,000 Tk.	E_{P2}	1,17,000	20 (B)	23,40,000 (C_{B2})
Total Energy from Panel	$E_{PT}= E_{P1}+ E_{P2}$	1,30,000		
Energy loss due to battery (Charging and discharging)	E_{PL}	5,200[6]		
Energy used from Panel	$E_{PU}= E_{PT} - E_{PL}$	1,24,800		
Energy from DG (Assume 30% of Total)	E_{DG}	53,485	15 [7]	8,02,285 (C_{DG})
Total Energy sell	$E_{TS} = E_{PU} + E_{DG}$	1,78,285	25 (S)	44,57,142 (T_S)
Yearly Running Cost (employee + other cost)				4,00,000 (C_R)
Cost per year				35,42,000 $T_C= C_{B2}+C_{DG} +C_R$
Net Profit per year				9,15,142 $T_P=T_S - T_C$

The total Energy sale may be given by,

$$T_{S1}= (E_{P1}+ E_{P2} - E_{PL} + E_{DG})*S \dots \dots \dots \dots \dots \dots (6.2)$$

The total cost per year is given by,

$$T_{C1}= E_{P2}*B+C_{DG} +C_{R1} \dots \dots \dots \dots \dots \dots \dots (6.3)$$

---

[6] 5% of the total generation by solar

[7] Energy cost by Diesel Generator is assumed same as Sandwip 100KWp Microgrid

And the net profit per year is given by,

$$T_P = T_S - T_C \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6.4)$$

where,

Usable energy from the Panels of entity 1per year = E_{P1}
Total energy buy from entity 2 (Total 90KWp) = E_{P2}
Total Energy from Panel, $E_{PT} = E_{P1} + E_{P2}$
Energy loss due to battery (Charging and discharging) =E_{PL}
Energy used from Panel, $E_{PU} = E_{PT} - E_{PL}$
Energy from DG (Assume 30% of Total)= E_{DG}
Yearly Running Cost (employee + other maintenance cost)= C_{R1}

Initial investment for Entity 2 is given in Table 6.3.

Table 6.3: Initial investment for Entity 2

Components	**Notation**	**Size**	**Price Breakdown**	**Total**
Panel	C_{P1}	2KW$_p$	2,000*60=6,00,000	1,20,000
CPU	C_{CPU}	20,000 per KW$_p$		40,000
Others	C_O			20,000
Total	C_{T2}			1,80,000

The installation cost for entity 2 is given by

$$C_{T2} = C_{P2} + C_{CPU} + C_o \ldots \ldots \ldots \ldots \ldots (6.5)$$

where,

C_{P2}= Cost for solar panel by entity 2
C_{CPU}= Cost for CPU
C_o= Other costs

Yearly cost calculation for entity 2 is given in Table 6.4

Table 6.4: Yearly cost calculation for entity 2

Item	**Total energy sale**	**Unit price of energy**	**Total**
Usable energy from the Panel per year	2600KWh	Selling price 20	52,000
Running cost		2% of initial cost	3,200
		Net Profit per year	47,800

Yearly Running Cost (employee + other maintenance cost)= C_R

The total Energy sale may be expressed as

$$T_{S2} = E_{P2} * B \ldots \ldots \ldots \ldots \ldots \ldots (6.6)$$

The total cost per year is given by,

$$T_{C2} = C_{R2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6.7)$$

And the net profit per year is given by,

$$T_{P2} = T_{S2} - T_{C2} \ldots \ldots \ldots \ldots \ldots \ldots \ldots (6.8)$$

Further increase of demand may be met by adding more solar panels by entity 2. This may require additional storage or backup. This storage/backup service may be incorporated by the entity 1 or by the entity 2. Results of these analyses are included in chapter 7.

6.8 Summary

The proposed model can be used as an alternative and supplement to the traditional power systems. As the scale of the unit is assumed to be smaller than the unit of a traditional large renewable energy microgrid, but larger than the unit of a solar home system, this will penetrate a significant percentage of renewable energy into the national generation. Due to its easy installation and maintenance, it will require less installation time and thus would allow a quicker growth of penetration of renewable energy into national energy production. It is logical that this inrush will unlock the power market for the common people. Besides these, the rate of global warming will decrease. The various components of the proposed model have been described in this chapter as well as an relevant example of policy description to implement this model. The features of this model, along with the policy, analyses of economic feasibility and projection of the installed capacity will be discussed at the next chapter as well as the results obtained from the analysis described in Chapter 4, Chapter 5 and Chapter 6 using the developed software routines.

CHAPTER 7

RESULTS AND DISCUSSION

In chapter 4, the tilt angle of the solar panels has been optimized to generate electricity to match with a specific load demand pattern. Analyses of the demand and generation of electricity by using the distributed` energy resources in a local microgrid have been proposed and the implementation process has been discussed in chapter 5. Finally, considering the overall aspects of electricity generation, distributed energy resources and the quick penetration of renewable energy resources in power generation, a novel model named "Consumer is Producer" has been proposed and described in chapter 6. This chapter will present the results of the three major propositions (in Chapter 4, Chapter 5 and Chapter 6) and discuss the results in a greater detail.

7.1 The Tilt Angle Optimization of Solar Panels and Its Benefits

In this analysis, it is found that, the maximum demand for an isolated grid is not met at the default tilt angle of solar panel; rather, it depends on the demand pattern as well as the generation pattern. Our demand is higher in July and around it and lower at November to February of a year. However, the generation of solar PV is not same as the demand pattern. The idea about the best matching pattern of generation at different tilt angles with the demand profile could be best comprehended from their correlation co-efficients. These are shown in the Table 7.1

Table 7.1: The correlation co-efficient (CC) of generation at Dhaka with national demand profile and generation at Chittagong with Sandwip microgrid demand profile.

Tilt Angle	**CC (Dhaka)**	**CC (Snadwip)**
5^0	0.159	0.156
6^0	0.111	0.103
7^0	0.062	0.048
8^0	0.012	-0.009
9^0	-0.037	-0.068
10^0	-0.087	-0.127
11^0	-0.136	-0.186
12^0	-0.182	-0.244
13^0	-0.228	-0.301
14^0	-0.271	-0.355
15^0	-0.312	-0.406
16^0	-0.352	-0.454
17^0	-0.388	-0.497
18^0	-0.421	-0.537
19^0	-0.452	-0.574
20^0	-0.480	-0.607
21^0	-0.506	-0.637
22^0	-0.530	-0.664
23^0	-0.551	-0.689
24^0	-0.571	-0.711
25^0	0.589	-0.731
26^0	-0.605	-0.748
27^0	-0.620	-0.764
28^0	-0.634	-0.778

From Table 7.1, it is found that, at the default tilt angle (23^0), the co-efficient is negative, thus there is a bad pattern match. Decreasing the tilt angle will results a better co-efficient and thus a better pattern match of demand and generation. On the other hand, total yearly output will decrease when the tilt position is shifted from default. In this case, 5^0 tilt angle may not provide the power to maximize the demand met although it has a better CC.

The analyses have been done for both of the national demand profile considering the generation profile of Dhaka and for the demand profile of the newly formed microgrid at Sandwip considering the generation profile of Chittagong (nearest observation point to Sandwip by NREL).

Demand and generation for the default tilt angle (23^0) and optimum tilt angle (12^0) for the national load profile have been shown in Figure 7.1.

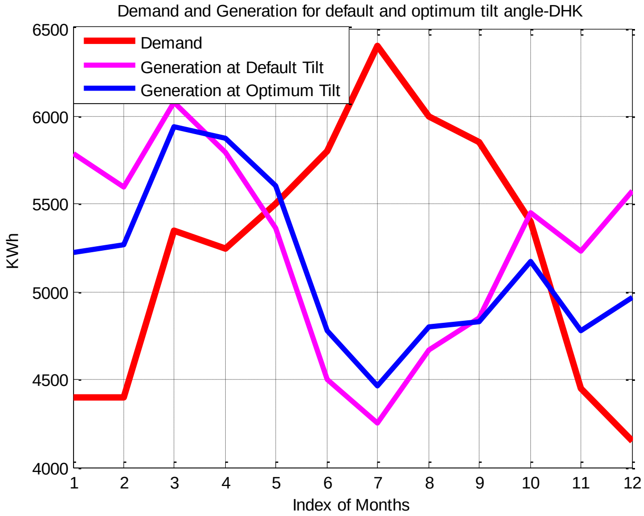


Figure 7.1: Demand and generation for the default tilt angle (23^0) and optimum tilt angle (12^0) -case study Dhaka.

From the above figure, it can be noted that, the demand is higher from the June to October over the year. At this period, the demand cannot be met by the solar panel, alternate resources of energy is needed. However, the curve for the optimum tilt is closer to the demand curve than that for the default tilt angle. Thus the demand met at optimum tilt will be more than that at default tilt. These are shown in Figure 7.2.

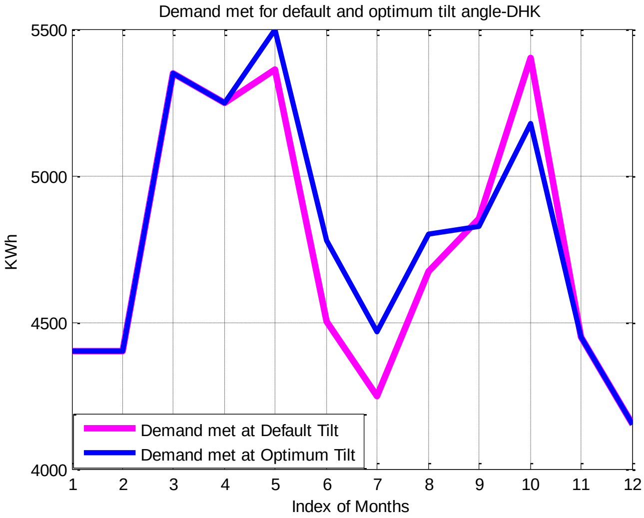


Figure 7.2: Demand met for default and optimum tilt angle-case study Dhaka.

As the demand cannot be met by panel for a period over the year, there would be shortage at that period. Shortage will be less for the optimum tilt. This is shown in Figure 7.3

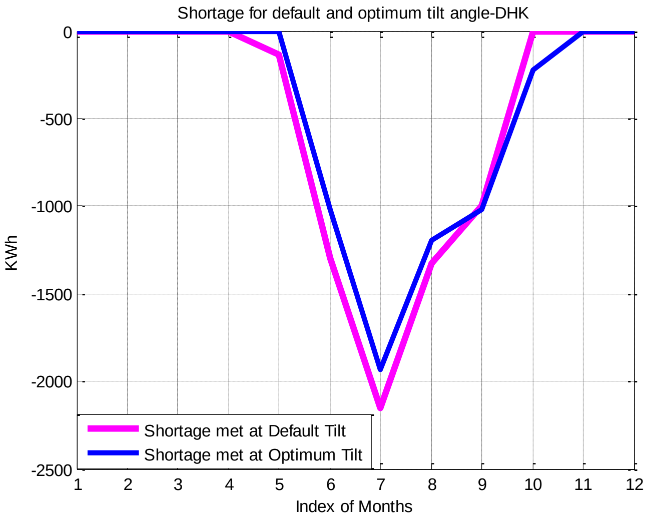


Figure 7.3: Shortage at default tilt and optimum tilt angle position- case study Dhaka.

The results are summarised in numerical figures as follows:

(a) Yearly total demand: 62,950 KWh
(b) Yearly total Generation at 23^0 tilt angle: 63,158KWh
(c) Yearly total Generation at 12^0 tilt angle: 61,705 KWh
(d) Yearly total shortage at 23^0 tilt angle: 5,910 KWh
(e) Yearly total shortage at 12^0 tilt angle: 5,400 KWh
(f) Yearly demand met 23^0 tilt angle: 57,040 KWh
(g) Yearly demand met 12^0 tilt angle: 57,550 KWh

The result of the analysis for the demand profile of the microgrid of Sandwip and considering the generation profile of Chittagong is given here. The tilt optimum angle for this case is found around 9^0 tilt. Demand and generation for the default tilt angle (23^0) and optimum tilt angle (9^0) for the national load profile have been shown in Figure 7.4.

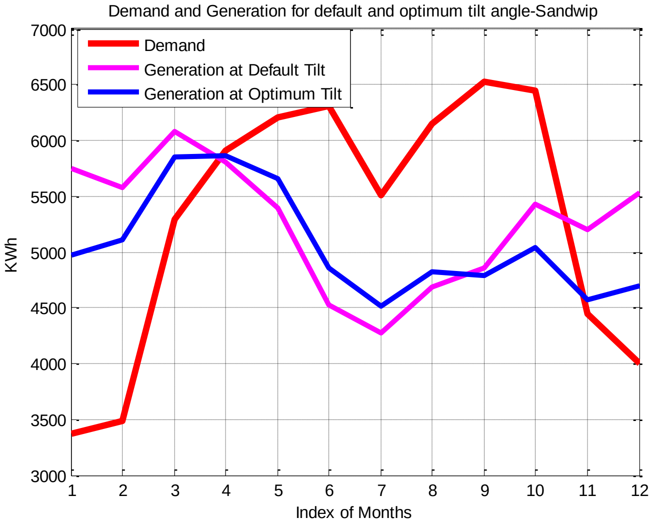


Figure 7.4: Demand and generation for the default tilt angle (23^0) and optimum tilt angle (9^0)-case study Sandwip.

It is also true for Sandwip microgrid that, the demand is higher from the May to October over the year. At this period, the demand cannot be met by the solar panel, alternate resources of energy is needed. However, the curve for the optimum tilt is closer to the demand curve than that for the default tilt angle. Thus the demand met at optimum tilt will be more than that at default tilt. These are shown in Figure 7.5.

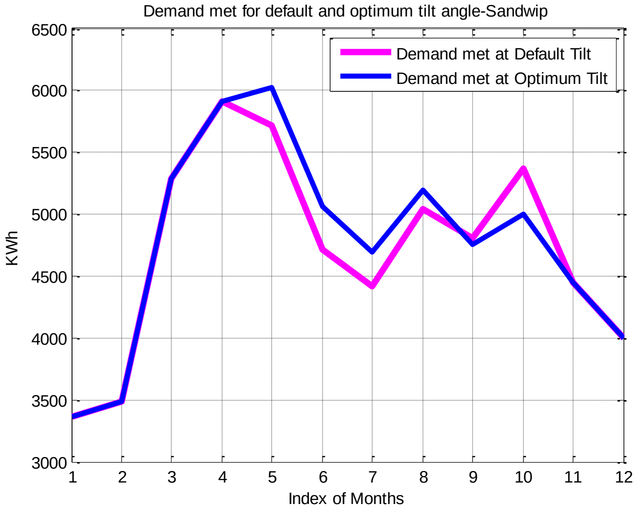


Figure 7.5: Demand met for optimum and default tilt angle-case study Sandwip.

As the demand cannot be met by solar panel for a period over the year, there would be shortage at that period. Shortage will be less for the optimum tilt. This is shown in Figure 7.6

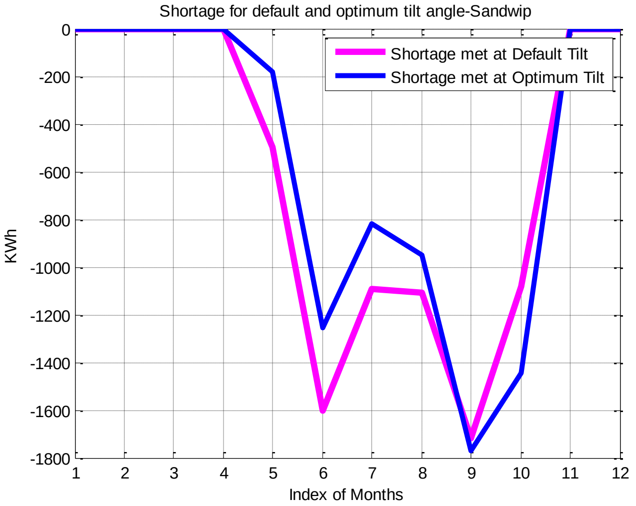


Figure 7.6: Shortage at default tilt and optimum tilt angle-case study Sandwip.

The results are summarised in numerical figures as follows:

(a) Yearly total demand: 63,641 KWh
(b) Yearly total Generation at 23^0 tilt angle: 66,244 KWh
(c) Yearly total Generation at 9^0 tilt angle: 63,844 KWh
(d) Yearly total shortage at 23^0 tilt angle: 70,95.5 KWh
(e) Yearly total shortage at 9^0 tilt angle: 64,14KWh
(f) Yearly demand met 23^0 tilt angle: 56,546KWh
(g) Yearly demand met 9^0 tilt angle: 57,227KWh

7.2 Sizing of Generation for Various DERs

Analysis of the demand and generation of electricity by using several distributed energy resources (primarily renewable energy) such as solar PV, biogas, wind, micro-hydro, storage devices and other fuel based generator in a local microgrid has been proposed and the implementation process has been discussed in Chapter 5.

In the current research, it has been identified that proper sizing for the generation units to meet the demand is an important factor. Combination of several renewable energy resources with different characteristics may help a particular power generation project to match the generation pattern with the demand pattern. To have a realistic model, the following major criteria have been adopted to obtain the optimum result.

(i) Minimum shortage as well as minimum surplus
(ii) Maximum demand met
(iii) Minimum cost of the alternative sources
(iv) Lower cost of energy
(v) Higher penetration of renewable energy
(vi) Lower installation cost
(vii) Lower running cost

The result of the optimization may vary with the basis of optimization. In Chapter 5, the result of the optimization based on minimum shortage thus maximum demand met, has been shown. The optimization algorithm has also modelled on the basis of installation cost, demand met, percentage of penetration, cost for alternative energy to meet the shortage, total cost for 10 years, cost of energy per KWh and other parameter. The model is developed in such a way that it would be possible to modify the program for other cases, which are not discussed in this analysis.

There may be multiple numbers of resources. This model is a general model in which combination of several types of resources could be analyzed. Considering N_1 number of size for resource R_1, N_2 number of size for resource R_2, and N_m number of size for resource R_m will have N_{total} number of different combination of resources.

where,

$$N_{total} = N_1 \ x \ N_2 \ x \text{ ------------ } x \ N_m \ \ldots \ldots \ldots \ldots \ldots \quad (7.1)$$

The analysis has been done based on this idea. Due to enormous size of combination and thus huge amount of data, only the analysis of a two resources, namely the solar PV and wind turbine, are taken into consideration.

Different combination of these two resources will produce different amounts of electrical energy over the year. Thus, the installation cost, demand met, running cost, cost of energy, percentage of penetration, carbon emission etc. will form a different combination. Table 7.2 shows the optimization according to the cost of energy. In this analysis the size of solar PV and the size of wind turbine have been considered as

```
solar=[1 10 15 45 50];wind=[0 1 2 5 10];
```

Table 7.2: The optimization according to the cost of energy

Combination No:	Solar PV KW_p	wind turbine KW	PV Generation KWh	Wind Generation KWh	Combined generation KWh	Shortage KWh	Surplus KWh	Optimum shortage or surplus KWh	Installation cost Tk.	Diesel Cost for 10 years Tk.	Total cost for 10 years while everything is constant	Cost of Energy pe KWh Tk./KWh	Demand Met KWh	Penetraion in %
20.00	45	10	52675	23369	76044	534	18596	18062	3650000	10689	3756891	6.539677	57447.65	0.990782
25.00	50	10	59478	23770	83248	528	21013	20485	4000000	10561	4105613	6.597027	62234.3	0.991586
24.00	50	5	59610	11427	71037	2232	13217	10986	3750000	44635	4196346	7.25766	57819.54	0.962836
19.00	45	5	55923	12030	67953	4671	8465	3795	3400000	93419	4334187	7.285857	59487.67	0.927197
23.00	50	2	62787	4529	67316	3183	11234	8052	3600000	63651	4236508	7.554173	56081.69	0.946299
22.00	50	1	62988	2433	65421	5580	7032	1453	3550000	111593	4665931	7.991142	58388.79	0.912775
21.00	50	0	58552	0	58552	5666	5581	-85	3500000	113320	4633199	8.74658	52971.55	0.903373
18.00	45	2	53375	4493	57867	8136	3248	-4888	3250000	162721	4877209	8.929498	54619.07	0.870352
17.00	45	1	52772	2433	55205	8831	2300	-6531	3200000	176625	4966254	9.387165	52904.73	0.856951
16.00	45	0	54840	0	54840	9539	1747	-7792	3150000	190789	5057892	9.526518	53092.77	0.847691
15.00	15	10	17897	24664	42561	16793	0	-16793	1550000	335866	4908661	11.53321	42561.09	0.717067
10.00	10	10	11832	22822	34654	28792	0	-28792	1200000	575836	6958356	20.07964	34653.78	0.546197
14.00	15	5	18356	11621	29978	30886	0	-30886	1300000	617716	7477162	24.94232	29977.81	0.492541

A system should be designed with the optimization based on majority of these parameters mentioned earlier such as, optimizing the system total cost after the optimization of energy cost and then optimization of maximum penetration and etc.

The optimization also depends on the limit or range of the parameters of optimization, like the boundary condition of that of in linear programming. Based on the range, the optimum size of the energy resources as DER for a microgrid could be possible. The results of the analyses based on solar, wind, biogas and diesel have been shown in the Appendix-E.

7.3 Positive Aspects of the "Consume is Producer" Model

The proposed model can be used to be an alternative and supplementary way to the traditional power system. Installation of large power plant based on renewable energy is good, but the scope for the implementation is not available everywhere. Moreover, larger power stations also need the evacuation system, which proves very costly although loss of this has been minimized. Hence, involvement of consumer people for large power stations is tough. On the other hand, the installed figure of SHSs is large (more than 3 million), but the amount of generated electricity is still not enough and is not contributing to the national grid. However, SHS is not a business model for the customers; rather for the NGOs. It is obvious that the number of investors for a smaller system increases exponentially than a larger system. In spite of this, the market of SHS is also almost locked for the common people. Hence, if the investment and policy are such that both of size of installation and investment remain at an optimum level, the production of energy will be high. As a result, the penetration of renewable energy would increase quickly, which will otherwise be difficult to achieve by incorporating the traditional large system and the SHSs. Extensive use of the new model will reduce the green house emission as well as the rate of global warming.

7.4 Key features of the Model

The model „Consumer is Producer" have some specialty over the other available models. Most of these features of this model are new or a strengthened version compared to the existing ones. These are described below:

(a) Suitable for the remote area considering the area, density of population, load profile, availabilities of alternative power resources.
(b) Minimization of the cost and loss due to Evacuation.
(c) Easy to install and maintenance. Easier installation as like as plug and play, thus minimum installation time.
(d) Economically feasible and cost effective.
(e) Creation of market for the common people. As a result, acceleration of general people into the power business should be possible. Thus, it will offer a higher rate of installation.

(f) Decrease the Carbon emission as well as lower greenhouse gas emission and decelerate the higher rate of global warming.
(g) Reliable load management system as well as source management system.
(h) Reliable for an extremely critical condition of the power system.
(i) Minimum installation and running cost.

7.4.1 Suitability

The concept is to start electrification from the consumer end, which is opposite to that of the conventional system. Interconnection of two or more users is easier for a smaller region. Therefore, CP model will be best fit for the remote area, where the availability of electricity is more important than the price of electricity. Few modification of this model will make it possible for urban areas as well.

7.4.2 Minimization of the cost and loss due to evacuation

Conventional power system needs transmission and distribution system for the evacuation of power. This process is associated with higher installation cost as well as loss (about 15% now). CP model has been eliminated the transmission system completely and the distribution network will exist only at low voltage level. Thus huge investment will be saved including the man power, time and costs associated.

7.4.3 Plug and play

The scale of the model CP is smaller than the power unit of traditional microgrid but larger than the SHS. Thus it is possible to have advantages from the two sides: advantages of traditional microgrid as well as of SHSs. The solar home system is almost a plug and play system and the traditional micro grids provide quality power. Hence the CP model is also a plug and play model that would provide quality power.

7.4.4 Minimum installation and running cost

Due to its plug and play features, the installation will be easier. It consists of less number of moving equipment for generation, critical devices for high voltage handling for transmission and distribution system is not present in this model. Therefore, it is obvious that the maintenance in CP model is easier and the cost for running and maintenance will also be less.

7.4.5 Reliable load management system as well as source management system

Each of the CPU (Consumer Producer Unit- Figure 7.1) has its own identification number and intelligence like the central controller. Each central controller is connected with some branch of the microgrid, but it will control only a few of the defined branches. The traditional system for load management by supressing load is to disconnect some branches from the grid. As a result, all the loads of those branches are disconnected from the power grid; thus a large number of consumers are affected. However, as the loads are categorized in the proposed CP model, the central controller will send command to the CPUs to disconnect some category of loads, when the generation is less than the demand. The alternative sources of energy and storage system are also connected with their own CPUs. The CPU is able to disconnect or connect any of its hand (power source or load) itself in case of any emergency or by following the command from the central controller. Moreover, the statuses of load and generation unit are always observed by the central controller. On the other hand, the control of voltage, frequency, real and reactive power, droop etc. can also be controlled by the central controller in the interconnected microgrid. It will control the frequency, voltage and other parameters for ensuring better of quality power. Hence, the source management is also reliable here.

7.4.6 Reliable under extremely critical condition of the power system

The power system proposed in the CP model is reliable under the extremely critical condition of the power system. Any fault in any branch will result disconnection of the faulty branch from the healthy branch. Therefore, the fault cannot spread over the healthy portion of the system. Once the faulty branch is isolated, each individual CPU will identify the fault, whether it is from itself or from the line. If it is a line fault, it will become disconnected from the line itself. If the fault is from itself, this will wait until the fault is removed automatically or manually. When the fault is removed, the synchronizer of the CPU will be connected to the line. However, if the fault is from the line, the CPU will check the status of the line until the fault is clear. By this way, the proposed model will still be able to serve the consumer under the extremely critical condition.

7.4.7 Economic feasibility and cost effectiveness

A relevant policy to implement this model has been discussed in the previous chapter. The policy has been discussed considering three types of entity. A mathematical model for this policy has also been discussed in Chapter 6. The payback period is an important factor for any business. The results of the analyses about the payback period for entity 1 and entity 2 are given here considering different selling price by each entity. To analyse these, an algorithm has been developed in MATLAB programming environment. It is included at Appendix-G.

In these analyses, it is assumed that entity 1 will buy power from entity 2. Power generated by entity 1 and purchased from entity 2 will be sold to the customers whether they belong to entity 2 or entity 3. The next few figures show the return of initial investment for both entity 1 and entity 2 considering a fixed selling price of entity 1. Figure 7.7 shows the buying price of energy from entity 2 versus the simple payback period while the price of sales is 20Tk. The same are shown in Figures 7.8, Figures 7.9, Figures 7.10 for a selling price of 25Tk., 30Tk. and 35Tk. respectively.

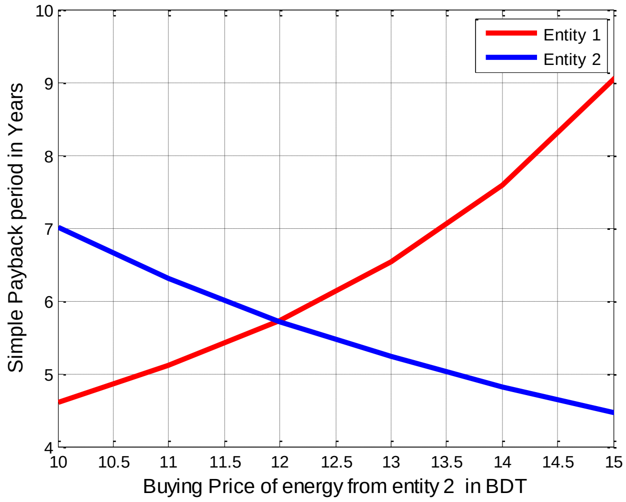


Figure 7.7: Price of purchase of energy from entity 2 VS period of return of initial investment for both of entity 1 and entity 2 while the selling price of energy by entity 1 is 20 Tk.

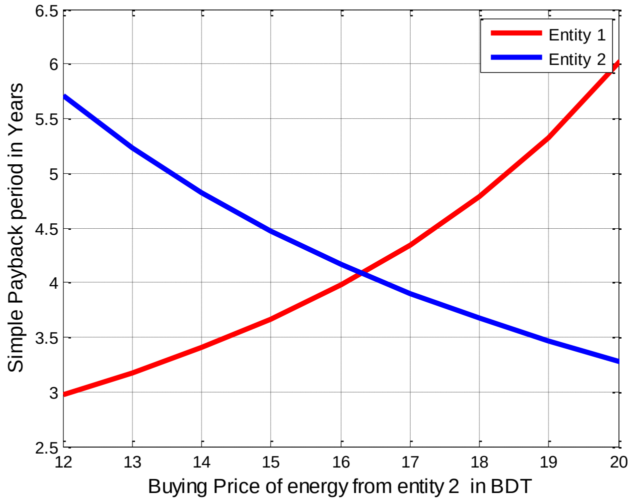


Figure 7.8: Price of purchase of energy from entity 2 VS period of return of initial investment for both of entity 1 and entity 2 while the selling price of energy by entity 1 is 25 Tk.

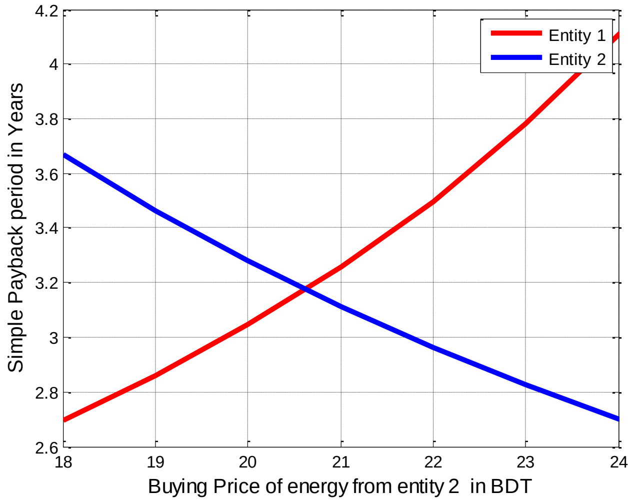


Figure 7.9: Price of purchase of energy from entity 2 VS period of return of initial investment for both of entity 1 and entity 2 while the selling price of energy by entity 1 is 30 Tk.

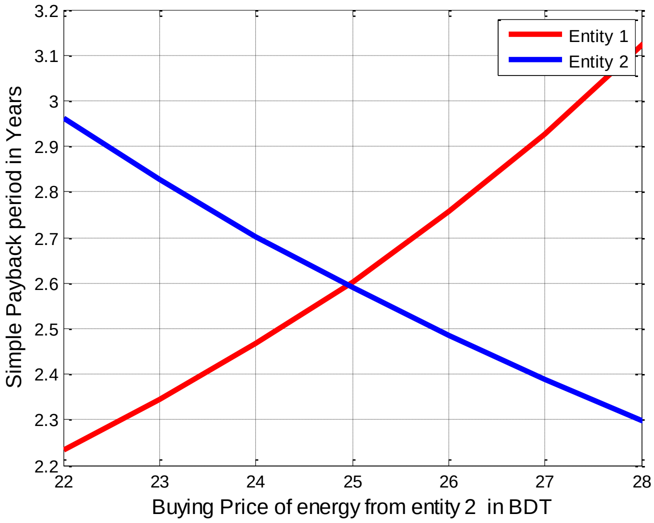


Figure 7.10: Price of purchase of energy from entity 2 VS period of return of initial investment for both of entity 1 and entity 2 while the selling price of energy by entity 1 is 35 Tk.

The next few figures show the payback period of the initial investment for both of entity 1 and entity 2 while the selling price of entity 2 is fixed. Figure 7.11 shows the price of energy sold by entity 1 to entity 2 or entity 3 in BDT versus simple payback period for both entities in years. Figure 7.12, Figure 7.13 and Figure 7.14 show the same for energy price of Tk. 15, Tk. 20 and Tk. 25 respectively. It is to be noted that as the selling price of energy by entity 2 is not changed, their payback period is not changing with the change of that of entity 1.

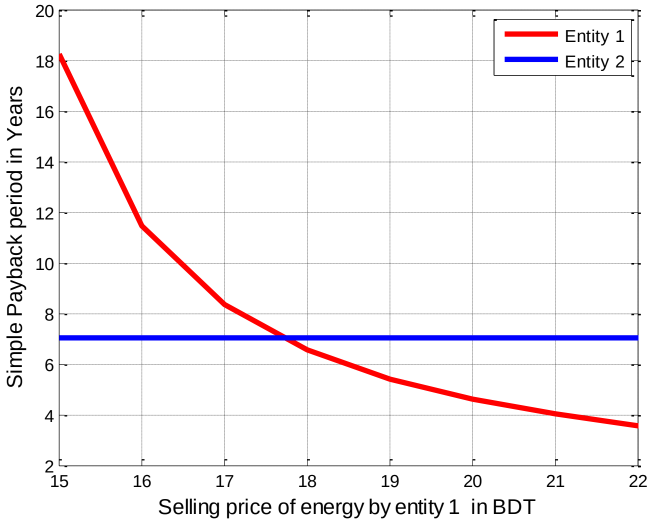


Figure 7.11: Payback period of the initial investment for both of entity 1 and entity 2 while the selling price of entity 2 is 10Tk.

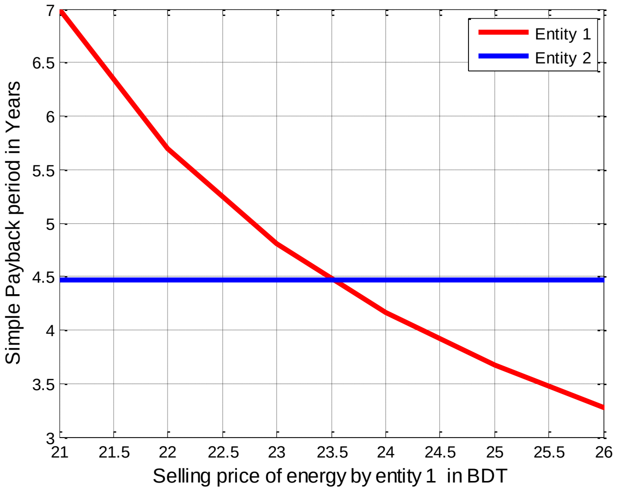


Figure 7.12: Payback period of the initial investment for both of entity 1 and entity 2 while the selling price of entity 2 is 15Tk.

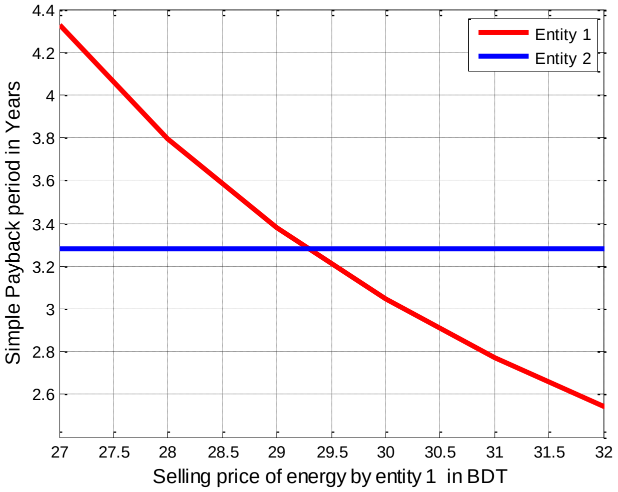


Figure 7.13: Payback period of the initial investment for both of entity 1 and entity 2 while the selling price of entity 2 is 20Tk.

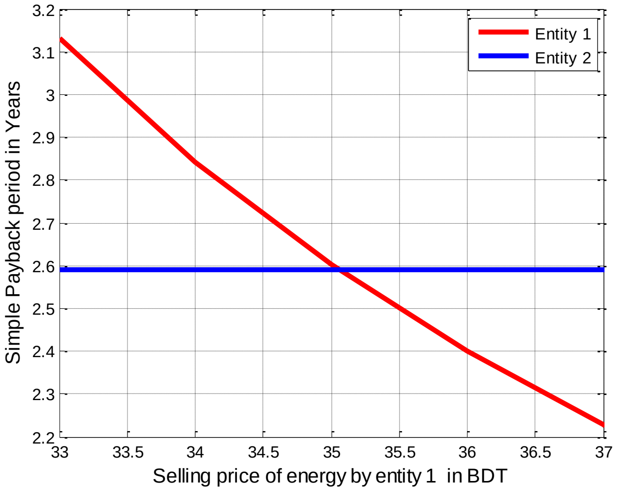


Figure 7.14: Payback period of the initial investment for both of entity 1 and entity 2 while the selling price of entity 2 is 25Tk.

Presently, the customers of the 100KW$_p$ Solar –Diesel Hybrid Microgrid, Sandwip are paying 30Tk. per unit of electricity. The analyses from the above figures show that, the payback period of both entities will be around 4 years keeping the price of electricity within a reasonable range. However, entity 1 and entity 2 may have different payback period depending on the selling and purchasing price of electricity. These could be obtained from the relevant Figures (Figure 7.7 to Figure 7.14).

7.4.8 Creation of the power market

The present power market is locked for the common people. Installation of large power station is not an easy task and involvement of such kind of power business is also hard for the common people. Due to the plug and play feature of the proposed model, it would have easier installation, lower installation cost, less time and labour for installation. As this is a local grid, the common people will be able to involve in power generation easily. As the model is cost effective and economically feasible, there will be an inrush for the installation of the CPUs. Hence, it will be able to create the market for the common people. As a result, acceleration of common people into the power business by means of renewable energy would become possible.

7.4.9 Lower carbon and greenhouse gas emission

Most of the traditional power sources release carbon-di-oxide and other green- house gases. Generation of power by those types of power sources will just increase the greenhouse effect, thus increasing the global warming. The proposed model accelerates the penetration of renewable energy into the power sector. Thus this model will reduce the carbon emission, greenhouse effect and the rate of global warming more effectively than by large scale centralized renewable power stations. The day is not far, when people will not count the money, rather the government will buy green energy without counting money.

Moreover, people will be motivated to produce their capita demand by themselves, as the name "Consumer is Producer" implies. However, proper policy and steps should be undertaken to promote this, like the SHS program by IDCOL. Proper design and debugging of the hardware system of this model will make the use of this model more convenient.

7.4.10 A comparison with „Solar Home System"

The price of an SHS (100W$_p$) is around BDT 35,000 excluding the components not related to generation (such as light bulbs, cable, DC fans etc.) Therefore, the price for 1MW$_p$ will be around BDT 350 Million. There is no fuel cost, but the system price of an SHS becomes high mainly because of the larger size of the battery/battery bank, which is used for three days autonomy.

In the proposed "Consumer is Producer" model, the installation cost for a 1MW$_p$ power generation system will be 60 Million BDT for panels and another 30 Million BDT (approximate) for battery, alternative energy resources and controlling equipment, which has already been shown in the Chapter 6. The installation cost for the generation unit is as much as that of the traditional power system, which may be obtained from the information of recently installed centralized power plants as shown below.

Installation Cost of Power Stations of North-West Power Generation Co. Ltd. (NWPGCL)

(a) Sirajganj 150 MW Power Plant: **BDT 11,448.00 Million (BDT 76.32 Million per MW).**

(b) Khulna 150 MW Peaking Power Plant **BDT: 15,422.37 Million (BDT 102.8158 Million per MW).**

(c) Bheramara 360MW Combined Cycle Power Plant: **BDT 41,404.80 Million (BDT 115.01 Million per MW).**

However, unlike the SHS for the alternative energy supply, there would be some extra fuel cost to meet the shortage as well as maintenance cost, whereas a traditional power plant requires a huge amount of fuel cost. In spite of this, if proper policies are undertaken by the government, the proposed "Consumer is Producer" model may have better performance over SHS as this model has some strong arguments over SHS. These are summarised in Table 7.3.

Table 7.3: Comparison of SHS and "Consumer is Producer" model

Comparison Criteria	**SHS**	**Consumer is Producer**
Consumer of the Business model for	The enlisted NGOs	Everyone
Scale of unit	10Wp~150Wp	1kW$_p$~5kW$_p$
Demand meet	Demand is forced to be limited by the size of the SHS	As much as need
Per W$_p$ installation Cost	Higher (400Tk. ~700 Tk.)	Lower (60 Tk. To 90 Tk.)
Contribution to the national grid	Nothing	Has option to be connected with the national grid
Contribution to the national generation	Insignificant	Significant
Penetration of green energy	Lower	Higher

7.5 Projection About the Installed Capacity

The SHS program of IDCOL has claimed to be the fastest growing program in the world. This was possible because of the appropriate policy that was undertaken. Thus, the policy taken to enhance any program is very important. Proper policy with subsidy and easy purchase would able to make the CP model achieve higher number of installations like IDCOL or even more. Considering the several arguments discussed in the previous sections and the rate of the installation of IDCOL, the possible installation capacity of the proposed "Consumer is Producer" model could be possible to forecast. This is shown in Table 7.4. The developed program by MATLAB has been included at Appendix-H

Table 7.4: Possible installation capacity of the proposed "Consumer is Producer" model

Year after starting the program	Rate of installation				
	200% of IDCOL	150% of IDCOL	100% of IDCOL	80% of IDCOL	50% of IDCOL
5 Year	404MW$_p$	303 MW$_p$	202 MW$_p$	161 MW$_p$	101 MW$_p$
10 Year	5020 MW$_p$	3765 MW$_p$	2510 MW$_p$	2008 MW$_p$	1255 MW$_p$
15 Year	43268 MW$_p$	32451 MW$_p$	21634 MW$_p$	17307 MW$_p$	10817 MW$_p$
20 Year	437263MW$_p$	327947MW$_p$	218631MW$_p$	174905MW$_p$	109316MW$_p$

It should be noted here that, this analysis has been done considering the number of installation of IDCOL"s SHS program, not the installed capacity of the SHS. To find the installation capacity of the proposed model, the number of installation has been multiplied by the unit capacity (2KW$_p$) of each CPU. This is illustrated in Figure 7.15

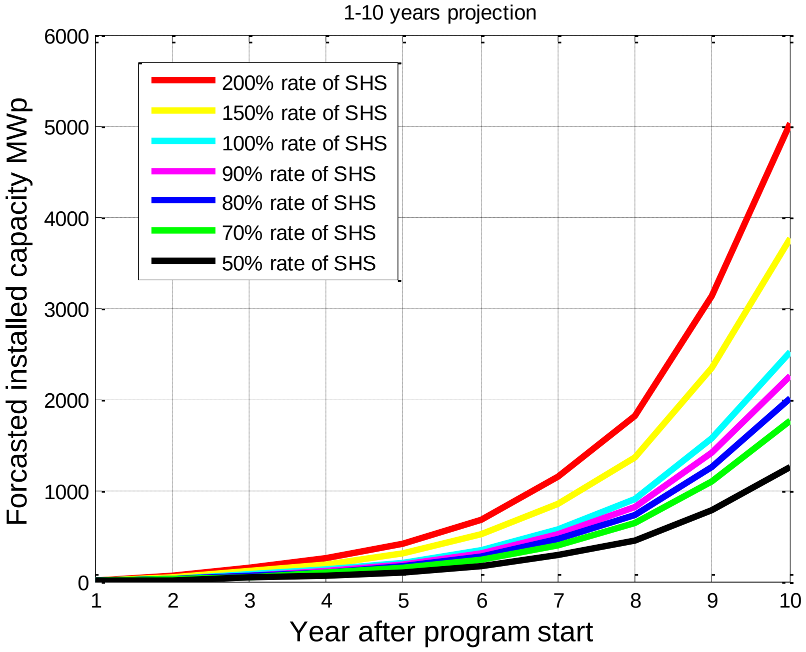


Figure 7.15: Forecasted installed capacity of the proposed model based on IDCOL"s installation number.

7.6 Summary

The results of the current research have been presented and discussed in this chapter. The next chapter will conclude the major findings and achievements of the current research and suggest some possible extensions of the current research.

CHAPTER 8

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

This chapter summarizes the findings and achievements of the current research. It also suggests some possible extensions to substantiate the current research in future.

8.1 Findings of the Current Research

The major findings of the current research may be summarized as follows:

8.1.1 Possibility of a local grid in a remote area named as microgrid

(a) A possibility of incorporating local grids namely “microgrids” in the remote area has been suggested, which would economically viable. This would also make interconnections of such microgrids possible.

(b) It has been found that the available distributed energy resources in Bangladesh like solar, wind, biogas, tidal, hydro, micro hydro etc. may be utilized in an optimum way using an appropriate optimization algorithm for its implementation.

(c) If the interconnected microgrids have surplus energy it can be delivered to the National grid so that the generated energy can be used elsewhere to meet the maximum energy demand of the country and thereby ensuring minimum overall shortage.

8.1.2 Optimization of distributed energy resources

Among the available renewable energy resources, not all of the renewable energy resources are suitable/available over the country rather only Solar, and biogas in some extent. Most of the renewable energy resources are intermittent and the characteristics of the generation may not be matched with that of the demand. Several types of resources may fit the characteristic of both more closely.

(a) Optimization of the distributed energy resources for maximum utilization of energy is possible by selecting the tilt angle and sizing the available distributed energy resources properly. Optimization depends on both the generation profile of a particular area and demand profile.

(b) Although it is suggested that for maximum energy generation over the year, the default tilt angle should be 23.5^0 south facing for the PV panels, it has been found by using the developed optimization algorithm that a 12^0 tilt angle meets the maximum energy demand if the demand profile of an area (Dhaka in this case) is assumed similar to the national demand profile of Bangladesh.

(c) However, the optimum tilt angle may vary for different generation and demand profiles. The same optimization algorithm has been run for the actual demand and generation profiles of Sandwip Island in Bangladesh. In this case, the optimum angle for maximum power utilization has come out to be around 9^0.

(d) Extensive studies of demand profiles of any region reveals that, the demand profile does not change abruptly each year. It is closely related with climate of the region. If the climate Bangladesh changes in such a way that people are using more heaters to keep their rooms hot during winter, the demand profile may change significantly. In this case, the tilt angle for optimum utilization will also be changed accordingly.

8.1.3 Integration of microgrids to the national grid to supply surplus power generated locally

Generation, transmission and distribution of power are done by some government"s authority and their co-partners. The common people are yet far from the power business. However, many of them are engaged with the business of power equipment, not with the power or energy business. Power markets are almost locked for the common people due to higher capital cost, which many of the common people cannot support; and also the policy. An implementation policy been discussed with proper example. Through the proposed model for microgrid, it is possible to meet the demand locally. As it may be a business model for everyone, engagement of a large number of populations is not impossible, thus higher the generation and higher the supply of energy. Due to shorter payback period, this may be able to attract all kinds of investors, small of big party, from country or out of the country. These will increase the percentage of penetration of renewable energy into the grid. Increased percentage of penetration of renewable energy into the grid will reduce the carbon emission and greed house effect quickly. In near future, microgrid based on distributed generation will be common everywhere. At that time interconnection of several microgrid will be possible, which will create microgrid network. By this way, the surplus energy could be supply to the nearest grid.

8.2 Contributions/Achievements of the Current Research

The major contributions/achievements are:

(a) Although it is always suggested that the tilt angle for a PV panel should be equal to the latitude of that place (for Bangladesh it is 23.5^0) for the maximum generation, an average of 12^0 tilt angle is suggested for the generation to best meet the demand of an isolated grid that has a similar load profile with national load profile of Bangladesh considering the generation profile of Dhaka. For Sandwip Island, it comes out to be around 9^0 to meet the demand profile. For other regions, the develop model is able to compute the optimum tilt angle.

(b) A common algorithm to optimize a power system based on renewable energy resources has been designed and implemented.

(c) A novel Model for Electricity generation, namely, “Consumer is Producer” has been proposed and presented.

8.3 Suggestions and Recommendation for Future Work

(a) The method of implementation of the generalized model of interconnection of microgrids to the national grid has been proposed in the current work. The practical realization of the model can be a new task to be taken as future extension of the current work.

(b) The function or the CPU in the proposed model is not an available embedded system in the market. However, the part of the CPU is available separately in the market. Therefore, the integration of these into an embedded system would be a new task.

(c) Possible recommendations: IDOCL‟s Solar Home System is claimed to be the number one fastest growing program in the world. This has happened due to the proper policy that has been undertaken. Proper policy with subsidy and other required facilities will make the proposed model to be more practicable. The policy makers should know about the model, and the person conducting the research should also be included in the policy making team.

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APPENDICES

APPENDIX-A
Some Snapshots of BPDB Annual Report

COMPARISION OF ELECTRICITY PURCHASE FROM RENTAL & QUICK RENTAL PLANT WITH PREVIOUS YEAR

Particulars	Nature of Fuel	FY-2012-2013			FY-2011-2012		
		Unit Kwh	Amount In Tk.	Cost/kwh	Unit Kwh	Amount In Tk.	Cost/kwh
AGGREKO, INTERNATIONAL LTD.-GHORASAL	Gas	884,425,530	5,231,589,134	5.92	139,417,050	1,805,676,912	12.95
AGGREKO, INTERNATIONAL LTD.-B.BARIA	Gas	508,846,126	2,845,339,222	5.59	736,632,820	7,099,382,215	9.64
AGGREKO, INTERNATIONAL LTD.-80 MW	Gas	483,915,253	2,881,617,531	5.95	509,408,110	2,788,542,607	5.47
SHAHJIBAZAR POWER CO. LTD.	Gas	584,089,553	1,464,712,398	2.51	589,434,221	1,424,254,855	2.42
DESH CAMBRIDGE, KUMERGOAN	Gas	55,257,868	160,357,389	2.90	47,681,827	145,613,892	3.05
ENERGYPRIMA, KUMERGOAN	Gas	260,345,140	936,034,121	3.60	267,446,540	947,309,548	3.54
ENERGYPRIMA, SHAHJIBAZAR	Gas	302,390,748	990,311,066	3.27	281,947,869	998,775,082	3.54
ENERGYPRIMA, FENCHUGONJ	Gas	300,594,910	1,048,744,783	3.49	182,038,110	394,533,007	2.17
ENERGYPRIMA, BOGRA	Gas	102,139,695	344,462,371	3.37	86,932,655	231,158,427	2.66
MAX POWER LTD.-GHORASAL	Gas	552,962,175	3,103,686,680	5.61	303,755,213	2,790,322,271	9.19
UNITED ASHUGONJ POWER LTD.	Gas	322,221,385	1,922,445,035	5.97	422,661,709	1,984,317,906	4.69
BARKATULLAH ELECTRO DYNAMICS LTD.	Gas	278,776,127	655,036,231	2.35	304,429,342	688,641,749	2.26
PRECISION ENERGY LTD.	Gas	283,698,139	1,323,730,792	4.67	420,311,731	1,499,121,116	3.57
VENTURE ENERGY RESOURCES LTD.	Gas	180,325,870	735,282,106	4.08	45,008,905	264,666,037	5.88
GBB POWER LTD.	Gas	166,971,964	461,915,282	2.77	168,362,186	459,755,876	2.73
SUB TOTAL - RENTAL - GAS		**5,266,960,483**	**24,105,264,141**	**4.58**	**4,505,468,288**	**23,522,071,500**	**5.22**
SUMMIT NARAYANGONJ POWER LTD.	HFO	526,067,928	8,823,683,817	16.77	413,851,725	6,438,974,593	15.56
KPCL -UNIT-2	HFO	463,511,424	8,053,598,427	17.38	608,436,636	8,826,720,060	14.51
KHANJAHAN ALI POWER LTD.	HFO	198,448,565	3,345,054,492	16.86	183,795,154	2,841,251,325	15.46
QUANTUM POWER NOWAPARA	HFO	89,385,883	2,297,396,401	25.70	153,722,409	2,633,997,383	17.13
IELCONSOURTIUM & ASSOCIATES	HFO	509,462,597	8,520,887,157	16.73	431,662,475	7,169,723,072	16.61
ENERGIS POWER CORPORATION LTD.	HFO	82,770,195	1,996,161,015	24.12	83,040,480	1,874,405,340	22.57
DUTCH BANGLA POWER & ASSOCIATES LTD.	HFO	476,301,024	7,847,214,067	16.48	444,262,392	6,866,734,661	15.46
ACRON INFRASTRUCTURE SERVICE LTD.	HFO	572,291,730	9,291,517,116	16.24	74,135,370	1,407,936,582	18.99
AMNURA(SINHA POWER GENERATION)	HFO	95,841,048	2,168,243,126	22.62	67,295,307	1,281,719,374	19.05
POWER PAC MUTIARA KERANIGONJ	HFO	349,580,064	6,420,285,449	18.37	73,382,880	1,387,800,826	18.91
NORTHERN POWER	HFO	109,141,143	2,299,534,198	21.07	36,854,994	578,779,580	15.70
SUB TOTAL - RENTAL - HFO		**3,472,801,601**	**61,063,575,265**	**17.58**	**2,570,439,822**	**41,308,042,796**	**16.07**
AGGREKO, INTERNATIONAL LTD.-55 MW	Diesel	100,611,860	3,322,649,551	33.02	133,406,571	2,869,958,204	21.51
AGGREKO, KHULNA(3 YEARS) LIQUID FUEL	Diesel	85,370,910	1,584,252,063	18.56	128,691,060	2,604,930,491	20.24
DPA POWER GEN. INT. LTD.	Diesel	93,613,130	2,579,535,337	27.56	132,678,070	2,744,599,920	20.69
QUANTUM POWER 100 MW BHERAMARA	Diesel	105,928,598	3,710,305,985	35.03	257,386,486	5,077,672,451	19.73
DESH ENERGY100 MW SIDDIRGONJ	Diesel	218,668,920	5,272,637,722	24.11	250,002,912	5,061,595,790	20.25
R Z POWER LTD.	Diesel	65,090,977	1,762,279,097	27.07	76,948,309	1,791,805,240	23.29
AGGREKO, INTERNATIONAL LTD.-80 MW ASHUGONJ		-	-	-	628,505,072	3,357,617,523	5.34
250 MW Elec. Purchase from INDIA		-	-	-	-	-	-
SUB TOTAL - RENTAL - DIESEL		**669,284,395**	**18,231,659,755**	**27.24**	**1,607,618,480**	**23,508,179,619**	**14.62**
TOTAL RENTAL PLANT		**9,409,046,479**	**103,400,499,161**	**10.99**	**8,683,526,590**	**88,338,293,915**	**10.17**

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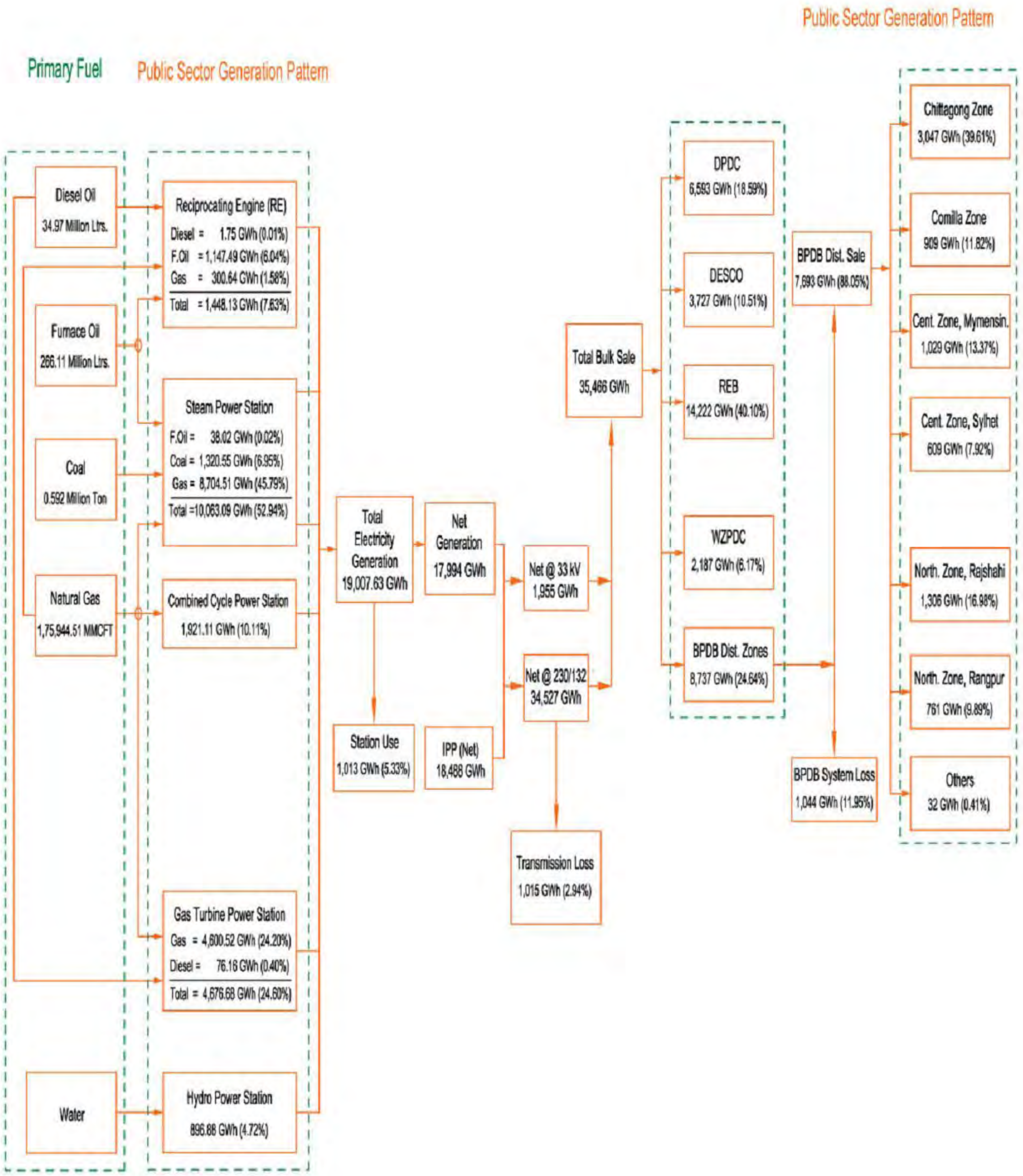
GENERATION COST OF BPDB'S OWN GENERATING PLANT

Sl. No.	Generating Plant under Power Station	Capacity	Net Generation kWh	Variable Cost				Fixed Cost		Total Generation Cost	Generation Cost Tk/kWh
				Fuel Cost Tk	Fuel cost Tk/kWh	Variable O & M	Variable O & M Tk/kWh	Total Fixed Cost	Fixed Cost Tk/kWh		
1	2	3	4	5	6=(5/4)	7	8=7/4	9	10=9/4	11=5+7+9	12=11/4
1	KARNAFULI HYDRO POWER STATION	230	893,797,875	-	-	121,861,466	0.14	665,665,716	0.74	787,527,183	0.88
	TOTAL WATER	**230**	**893,797,875**	**-**	**-**	**121,861,466**	**0.14**	**665,665,716**	**0.74**	**787,527,183**	**0.88**
2	WIND BASE POWER STATION, KUTUBDIA		-	-		50,565		2,413,173		2,463,738	
	TOTAL WIND	-	-	-		**50,565**		**2,413,173**		**2,463,738**	
3	BAGHABARI POWER STATION	171	1,315,642,010	1,327,063,222	1.01	272,275,135	0.21	414,873,233	0.32	2,014,211,590	1.53
4	GHORASHAL POWER STATION	950	3,300,771,048	3,083,866,911	0.93	348,660,926	0.11	2,595,367,945	0.79	6,027,895,782	1.83
5	CHITTAGONG POWER STATION, RAWZAN	420	559,241,076	694,927,906	1.24	282,288,226	0.50	941,502,513	1.68	1,918,718,645	3.43
6	SHIKALBAHA POWER STATION	210	381,645,608	1,000,821,805	2.62	99,523,372	0.26	765,538,365	2.01	1,865,883,542	4.89
7	KUMERGOAN GT POWER SYLHET	20	34,769,770	45,506,458	1.31	130,484,706	3.75	28,189,094	0.81	204,180,258	5.87
8	SYLHET 150 MG PEAKING POWER PLANT	150	631,796,005	621,360,090	0.98	556,209	0.00	81,341,928	0.13	703,258,227	1.11
9	FENCHUGANJ 2x 90 MW CCPP (1st & 2nd unit)	180	867,854,668	763,233,454	0.88	43,318,662	0.05	587,300,165	0.68	1,393,852,281	1.61
10	SHAHJIBAZAR POWER STATION	117	439,725,247	494,243,945	1.12	61,386,266	0.14	266,958,135	0.61	822,588,347	1.87
11	TONGI POWER STATION	109	338,247,146	374,208,799	1.11	256,610,858	0.76	300,060,486	0.89	930,880,143	2.75
12	SIDDIRGONJ POWER STATION	210	695,612,826	658,317,080	0.95	61,633,944	0.09	856,411,000	1.23	1,576,362,024	2.27
13	CHADPUR PEAKING POWER PLANT	150	671,273,296	482,918,312	0.72	1,463,989	0.00	89,992,916	0.13	574,375,218	0.86
14	SBU Haripur (cost of BPDB's book)							175,784,394		175,784,394	
	TOTAL GAS	**2,687**	**9,236,578,700**	**9,546,467,982**	**1.03**	**1,558,202,293**	**0.17**	**7,103,320,174**	**0.77**	**18,207,990,449**	**1.97**
15	BARAPUKURIA POWER STATION	250	1,156,420,520	5,381,781,158	4.65	286,513,583	0.25	931,258,730	0.81	6,599,553,471	5.71
	TOTAL COAL	**250**	**1,156,420,520**	**5,381,781,158**	**4.65**	**286,513,583**	**0.25**	**931,258,730**	**0.81**	**6,599,553,471**	**5.71**
16	KHULNA POWER STATION	170	31,862,242	874,541,045	27.45	94,569,281	2.97	643,218,440	20.19	1,612,328,766	50.60
17	BAGHABARI 50 PEAKING POWER PLANT	50	128,710,823	1,894,067,307	14.72	74,577,415	0.58	177,333,047	1.38	2,145,977,770	16.67
18	BERA PEACKING POWER PLANT	70	103,197,483	1,547,438,841	14.99	1,931,480	0.02	175,406,951	1.70	1,724,777,272	16.71
19	HATHAZARI PEACKING POWER PLANT	100	133,589,904	1,904,131,707	14.25	2,004,971	0.02	306,662,976	2.30	2,212,799,654	16.56
20	DOHAZARI PEACKING POWER PLANT	100	144,528,600	2,059,224,169	14.25	1,805,743	0.01	326,123,294	2.26	2,387,153,206	16.52
21	FARIDPUR PEACKING POWER PLANT	50	106,379,040	1,548,602,423	14.56	37,480,387	0.35	137,332,718	1.29	1,723,415,529	16.20
22	GOPALGONJ PEAKING POWER PLANT	100	208,464,082	3,122,146,387	14.98	83,768,005	0.40	258,815,193	1.24	3,464,729,585	16.62
23	DAUDKANDI PEACKING POWER PLANT	50	82,971,404	1,280,972,133	15.44	-	-	191,732,839	2.31	1,472,704,972	17.75
24	SHANTAHAR 50MW POWER PLANT	50	38,548,100	584,019,558	15.15	150,529	0.00	118,183,368	3.07	702,353,455	18.22
25	KATAKHALI 50MW POWER PLANT	50	38,045,952	576,015,764	15.14	297,731	0.01	114,278,419	3.00	690,591,914	18.15
	TOTAL HFO	**790**	**1,016,297,630**	**15,391,159,334**	**15.14**	**296,585,542**	**0.29**	**2,449,087,246**	**2.41**	**18,136,832,123**	**17.85**
26	BHERAMARA POWER STATION	60	28,152,279	808,348,907	28.71	139,183,395	4.94	208,618,093	7.41	1,156,150,395	41.07
27	BARISHAL GAS TURBINE POWER STATION	40	19,078,164	586,609,887	30.75	74,705,107	3.92	56,828,329	2.98	718,143,324	37.64
28	BARISHAL DIESEL POWER STATION	6	(3,000)	-	-	357,463	(119.15)	37,110,795	(12,370.27)	37,468,258	(12,489)
29	BHOLA DIESEL POWER STATION	8.36	-	864		1,025,287		22,419,330		23,445,481	
30	SAYEDPUR GAS TURBINE POWER STATION	20	15,547,340	431,064,500	27.73	354,662,058	22.81	48,112,285	3.09	833,838,843	53.63
31	RANGPUR GAS TURBINE POWER STATION	20	11,773,494	325,073,835	27.61	132,241,325	11.23	34,041,827	2.89	491,356,988	41.73
32	SAYEDPUR DIESEL GENERATOR		-	-		-		699,723		699,723	
33	THAKURGOAN DIESEL GENERATOR		-	-		-		2,601,567		2,601,567	
34	KUTUBDIA DIESEL GENERATOR	1.5	189,918	3,317,408	17.47	447,756	2.36	5,005,616	26.36	8,770,780	46.18
35	SANDIP DIESEL GENERATOR	2.64	412,227	8,136,568	19.74	1,053,330	2.56	3,357,649	8.15	12,547,547	30.44
36	HATIYA DIESEL GENERATOR	2.2	1,151,900	32,462,041	28.18	2,230,969	1.94	8,809,372	7.65	43,502,382	37.77
37	DGD, Dhaka		-	693,677		275,552		21,259,886		22,229,115	
	TOTAL DIESEL	**161**	**76,302,322**	**2,195,707,688**	**28.78**	**706,182,242**	**9.26**	**448,864,473**	**5.88**	**3,350,754,404**	**43.91**
	TOTAL GENERATION COST	**4,118**	**12,379,397,047**	**32,515,116,163**	**2.63**	**2,969,395,692**	**0.24**	**11,600,609,512**	**0.94**	**47,085,121,367**	**3.80**

ENERGY FLOW CHART
(FY 2013)



APPENDIX-B

Solar PV-Diesel Hybrid Micro Gird at Sandwip-A Case Study

Appendix-B describes a Solar PV-diesel hybrid microgrid which is located at Sandwip, an island of the district of Chittagong. It is an isolated island having more than a population of 300,000. It is detached from Chittagong mainland by a channel of about 75 kilometers. The island has a dynamic population with various public and private service offerings providing support to the general public including educational institutions, health service centers, small and medium enterprises, etc. However, due to its position and inaccessibility there is no possibility of grid electrification service in this area in the distant future. Despite shortage of reliable and consistent supply of electricity, use and willingness of use of various loads have been found in this region i.e. computers, printers, scanners, photocopy machine, refrigerators, color television, etc. The demand of electricity was met by local diesel generators at various places of the island independently. Recently, a microgrid has started its operation from October 2010. Expanding rural electrification is the key to the prosperity and development of rural areas as well as to fulfill the GOB"s vision of ensuring access to affordable and reliable electricity for all by 2020. It is well recognized that energy demand in our rural areas is increasing and supply of fossil fuel at subsidized prices is becoming an ongoing challenge for the government. Moreover, providing power without intensifying the effect of climate change is a priority for Bangladesh. There is also increased emphasis on increasing the energy conversion efficiency and promoting the use of alternate energy sources. Companies of Bangladesh on 17 December 2009 with an authorized capital BDT 20 million and paid up capital of BDT 10 million. The proposed shareholding structure PGEL is shown in Table B.1.

Table B.1: Shareholding Structure

No	Name of the Shareholders	Number of Shares	%
1	BRIDGE	50	25
2	IDF	50	25
3	UBOMOUS	50	25
4	REDI	50	25
	TOTAL	**2,000**	**100.00%**

Pre-Microgrid Description

The electricity demands of general shops in the markets of Sandwip are served by diesel generator based local grid. These are operated by local operators at different region and they provide services for about 5 to 8 hours per day. Besides, several shop owners have their own diesel generator for captive consumption. Average tariff rate being charged to the customers by the diesel operators currently range between BDT 53 per kWh and BDT 60 per kWh.Several key points were considered regard to the Project. Such as

(a) Sponsors involvement in the implementation of SHS program of IDCOL,
(b) adequate solar radiation in Bangladesh
(c) assessment of technical viability by PSE AG, Germany, appointed by KfW,
(d) Project‟s potential to save diesel
(e) availability of grant fund
(f) adequate market demand for electricity
(g) Reduction in effective per unit cost of electricity to be offered by the Project in comparison to the existing pricing

Why New Microgrid

The proposed Project envisages supplying reliable and consistent supply of quality electricity to the local commercial shops, health centers and schools at an affordable, reasonable and competitive price to encourage income generating activities more than before and enhance standard of living of the local people.

The Microgrid

The microgrid is a solar PV-diesel hybrid AC microgrid. The official name of this project is “100kW Solar Mini Grid” which is situated at Enamnahar Market, Sandwip. The size of the project area is about 0.6 acres. It consists of a 100-kW solar photovoltaic (PV) with a 40-kW diesel generator in order to ensure adequate power supply during periods of low solar radiation. However, it is not supplying all over Sandwip rather only three markets Enamnahar Market, Khonterhat and Panditerhat as well as their adjacent area. The target of the project was to supply electricity to adjacent 390 shops, 5 health centers and 5 schools.

However, the present condition is different from the target. It is shown in Table B.2.

TABLE B.2: No. of connections as of July, 2014

SL No.	Consumer Type	Nos.
01	Commercial shops	189
02	Financial Institutions/Bank/Govt. office	15
03	School	02
04	Mosques	05
05	Hospitals/Pathological Lab	08
06	Households	49

Energy consumption for different category is shown in Table B.3.

Table B.3: Energy Consumption Category

SL No.	Type of Consumer (Description of the Consumer)	Nos.	Average Consumption	Average Bill Tk./month
01	Large(Consumption more than 100kWh/month)	15	183	6,269
02	Medium (Consumption 41-99kWh/month)	38	38	2,203
03	Small (Consumption less than 40kWh/month)	215	215	624

Particulars

Asantys Systems was responsible for supplying the required machineries and accessories and installing the grid. The solar modules were procured from KYOCERA and inverter, sunny Web box and battery fuse were procured from SMA, Solar Technology AG of Germany. The batteries that are being used as storage were procured from HOPPECKE, Germany. Moreover, PSL is now providing O&M services and training to the management of the Project. Total cost of the proposed Project was about BDT 57.71 million. Breakdown of total cost is shown in Table B.4.

Table B.4: Breakdown of total cost of the project

Particulars	Amount (BDT)	Amount(BDT)	% of Project costs
Land and Land Development		1,260,000	2.18%
Civil Construction		2,400,000	4.16%
Equipment			
Solar Modules (100 kW)	19,500,000		
Grid Tie, SI Inverter	7,725,000		
Backup Diesel Generator – 40 kW	500,000		
Accessories	500,000		
Batteries – 48 V, 18000 Ah	10,124,334		
Total Equipment		**38,349,334**	**66.45%**
Transportation		725,000	1.26%
Distribution & Others			
Distribution Line (5 km)	1,050,000		
AC Household Meters	1,000,000		
Control Room, Structure & others	800,000		
Total Distribution & Others		2,850,000	4.94%
Import Duty & Clearance Cost		7,403,121	12.83%
Technical Assistance		3,136,200	5.43%
Contingency (3% of capital cost)		1,589,624	2.75%
TOTAL PROJECT COST		57,713,279	100.00%

The system design is based on AC-coupled bus concept. The main idea is to provide direct solar energy to the consumer via an AC bus through converters, when the converter energy (radiation) meets with the energy demand. Surplus is being charged via a so called “sunny island” charger into the batteries.

The size of the solar micro-grid project is 100 kW accompanied by 40 kW Diesel. The solar microgrid is given in Figure B.1, which is a combined operation of several sub-systems.

The Solar PV modules are the main power generation system that is operational during daytime. About 60 kW of the PV modules are directly connected to 6 Sunny mini central (SMC with MPPT) inverters which convert the DC power to AC power at 220V and supply to the micro-grid distribution line at all times. Three phase configuration of the AC distribution line is configured through the Multi-cluster box, which is the interface for all connectors and control. The unused portion of the power in the distribution line is stored into the batteries through 12 bidirectional inverters called “Sunny Islands” in 4 clusters. During daytime additional 40 kW PV power is stored into the same battery bank through DC battery chargers (SIC40 with MPPT). When the grid power is not available, mainly during evening hours the plant uses power from the battery bank. During the worst season of solar radiation, and on cloudy days, backup power is provided by the 40kW Diesel generators. The layout of the solar microgrid using four cluster “Sunny Island” inverter is shown in Figure B.1.

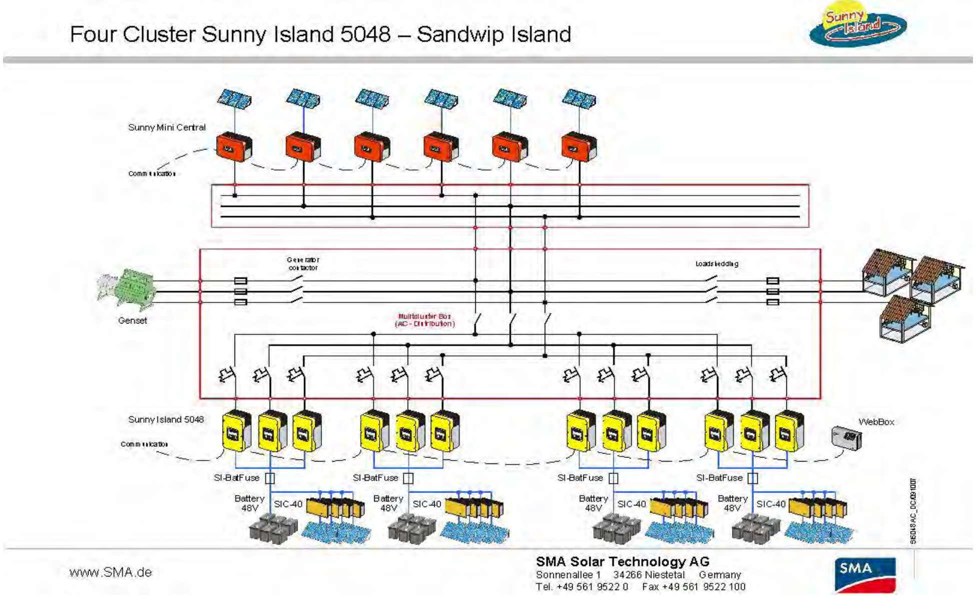


Figure B.1: Solar microgrid layout using four cluster “Sunny Island” inverter

The Web-box is the communication center of the solar power plant which is accessible by internet. It can be used to monitor daily performance of the system and for all trouble shooting. With continuous data logging the Web-box is used for remote system configuration, data storage etc. So the system can be remotely monitored, and designated authority can remotely reconfigured as needed (eg. SOC of battery banks).

Description of Major Equipment

The major components of the microgrid project are

- (a) Photovoltaic (PV) Module
- (b) Grid Inverter
  - (i) Multi cluster box
  - (ii) Bidirectional Inverter
  - (iii) Battery Main Switch
- (c) Inverter
- (d) Charger (DC)
- (e) Sunny Web box & Battery Fuse (Communication Kit)
- (f) Deep Cycle Industrial Battery
- (g) Diesel Generator

Photovoltaic (PV) Module

The PV Modules used in this project are polycrystalline and highly efficient. There are 500 nos. of 200Wp PV Modules. The PV Module is procured from Kyocera. The major features of the proposed PV module model KC200GH-2P are as follows:

Table B.5: Solar Module Specification

Particulars	Model KC200GH-2P
Maximum Power (Pmax)	200Wp (+10%/-5%)
Maximum Power Voltage (Vmp)	26.3V
Maximum Power Current (Imp)	7.61A
Open Circuit Voltage (Voc)	32.9V
Short Circuit Current (Isc)	8.21A

Grid Inverter

It consists of the following:

- (a) Multi cluster box
- (b) Bidirectional Inverter
- (c) Battery Main Switch

Multi Cluster Box: There is a multi-cluster box. The model used is SMA MC Box-12.3 Option Code 30001 Major Features of this are

- (a) 3-phase Multi cluster-Box for the easy installation of stand-alone and hybrid systems with Sunny island 5048 up to a power range of 110 kW.
- (b) Completely wired and equipped with a main connector for PV and wind turbine systems.
- (c) Connection for a maximum of 4 clusters consisting of three Sunny Island 5048 devices each.
- (d) Integrated generator and load-shedding contactor.
- (e) The communication cables necessary for the installation are included

Bidirectional Inverter: There are 12 nos. of bidirectional inverter. The model used is SMA SI 5048 Option Code 0031. Major Features of this are:

(a) Bi-directional battery inverter for setting 3-phase stand-alone systems
(b) Modularly extendable
(c) Multi-cluster operation
(d) High efficiency
(e) Intelligent battery management for maximum battery lifetime
(f) Charge level calculation
(g) Excellent overload capability
(h) Integrated display and control panel
(i) Integrated protective functions, DC fuse
(j) Output: short-circuit proof
(k) Operating temperature range: -25 °C ... +50 °C
(l) Continuous charging current of the battery at 25 °C for 100 A battery type: lead NiCd, battery capacity 100 - 10,000Ah

Battery Main Switch: There are 4 nos of battery main switch and the model used is SMA BATFUSE-B.03 Option Code 30. The main features are as follows:

(a) 1-pole NH 1 battery fuse as a load disconnecting switch for up to 3 Sunny Islands
(b) 6 DC input ports (2 x Battery an 4 x Sunny Island Charger)
(c) 1 x auxiliary voltage output with 8.6 x 250
(d) A fuse plug with 6 additional replacement fuses for Sunny Island 5048

Inverter

There are 6 nos. of inverter. The model is SMA SMC 11000TL-11 Option Code 8000x1. Main Features of the inverter are

(a) Inverter for the feeding-in of solar electricity into the low-voltage grid in grid-parallel operation
(b) Transformer-less with all current sensitive failure current monitoring unit
(c) Opti-Cool cooling concept - maximum output up to 40°C ambient temperature
(d) Integrated display; suitable for indoor/outdoor mounting
(e) SMA Grid Guard grid monitoring
(f) Electronic Solar Switch (ESS) circuit-breaker: integrated protective functions
(g) Input: thermally monitored varistors, ground fault monitoring, reverse polarity prevention via short-circuit diode
(h) Output: short-circuit proof (current regulation).

Charger (DC)

There are 16 nos. of chargers of Model: SMA SIC 40-MPTOption Code 000. Main features of the charger are as follows:

(a) MPP solar charge controller.
(b) Automatic regulation and single point of operation from Sunny Island
(c) Up to four devices can be connected in parallel, modularly extendable, active MPP tracking, efficiency > 98 %, suitable for indoor and outdoor installation due

to IP65, fanless. Integrated protective functions: short-circuit / reverse polarity / overload / excessive or insufficient voltage / overheating and undercooling; operating temperature range: - 25°C ... +60 °C;

(d) Battery type: lead;

Sunny Web box Communication Kit

There is one communication kit of model SMA Sunny WebBox Option Code 2001. The main features are as follows:

(a) Multi-functional data logger and communication center for setting parameters
(b) System monitoring, remote diagnostics, archiving data and visualization of up to 50 inverters
(c) The data is automatically transferred to Sunny Portal if desired
(d) The Sunny WebBox is easily operated using a web interface
(e) The data is accessed using a SD card or the integrated FTP server

Deep Cycle Industrial Battery

System requirement 48V, of 18000 Ah total are met with series and parallel connection of 2V of 96nos. of industrial batteries. Battery banks with tubular plate industrial batteries of 48 Volt (made up of 2V units) 18000 Ah total is proposed for 100 kW PV system. Due to the tubular configuration of the positive plate, these batteries are designed to withstand deep discharge and have a longer life. The proposed batteries are manufactured in Germany, with a service warranty of 10 years. Technical Specifications of the batteries are given below.

(a)	Rated Voltage	: 2V
(b)	Battery Capacity	: 3000Ah@10hr
(c)	Plate Type	: Positive Plate Tubular
(d)	Brand	: HOPPECKE

This is the first solar PV-diesel microgrid in Bangladesh. The characteristics of demand, generation, and increase of demand and other factors of this project are very important. Analysis of these parameters and other learnings from this project will be helpful for designing new microgrid.

APPENDIX-C
MATLAB Implementation Routine for "Tilt Angle Optimizaiton"

C.1 Finding Correlation of Monthly Demand of Last Three Years (2011, 2012 and 2013)

```
clear all
clc
format long g
y11=[2320.31 2308.32 2728.67 2849.11577 2917.83 2990.17 3161.45
3244.47 3083.4 3226.86 2502.36 2558.81];
y12=[2722.57 2717.84 3063.04 2881.46 3202.52 3307.1 3735.82 3677.42
3455.29 3226 2644.56 2589.76];
y13=[2645 2726.51 3501.76 3592.05 3600 3774.33 4080.22 3677.63 3725.15
3472.81 2923.01 2783.29];
yav=(y11+y12+y13)/3;
Y=[y11 y12 y13];

c12=corrcoef(y11,y12);
c12=c12(1,2);
c13=corrcoef(y11,y13);
c13=c13(1,2);
c23=corrcoef(y13,y12);
c23=c23(1,2);
cav =(c12+c13+c23)/3;

itta=1000;
r=0.3

for i=1:itta
    for j=1:12

    y(j)=y11(j)*(1-r+2*r*rand());
    yy(i,j)=y11(j)*(1-r+2*r*rand());
    end

    c=corrcoef(y11,y);
    b(i)=c(1,2);
end

coef=sum(b)/length(b)

%c12,c23,c13 are year to year correlation coefficient
%coef is the average correlation coefficient of the demand of 2011 and
%the %predicted demand that varies randomly within +r to -r of the
demand 2011.
```

C.2 Correlation of Demand and Generation at Various Angle

```
clear all
clc
format short g

[A,B] =xlsread('optangle');
B=B(:,1);
B=B(2:end,:);
C=A(1,:);
C=C(:,2:end)
angle=C(:,2:end);
D=A(2:end,:);
dem=D(:,1)
G=50*D(:,2:end)
for i=1:length(D)-1
    k=corrcoef(D(:,1),D(:,i+1));
    coef(i)=k(1,2);

end

ang_cor=[C; coef]'
xlswrite('cor_coef.xls',ang_cor,'Sheet1');

plot(dem,'k', 'LineWidth',3)
grid on
hold on
plot(G(:,1),'r', 'LineWidth',3)
plot(G(:,5),'c', 'LineWidth',3)
plot(G(:,9),'g', 'LineWidth',3)
plot(G(:,13),'b', 'LineWidth',3)
plot(G(:,17),'m', 'LineWidth',3)

legend('Demand','Generation at 23 degree','Generation at 19
degree','Generation at 15 degree','Generation at 11
degree','Generation at 7 degree')
xlabel('Index of the months', 'FontSize',15);
ylabel('Demand and Generation for variuos tilt angle', 'FontSize',15);

figure
grid on
hold on
plot(dem-G(:,1),'r', 'LineWidth',3)
plot(dem-G(:,5),'c', 'LineWidth',3)
plot(dem-G(:,9),'g', 'LineWidth',3)
plot(dem-G(:,13),'b', 'LineWidth',3)
plot(dem-G(:,17),'m', 'LineWidth',3)
legend('surplus or shortage  at 23 degree','surplus or shortage at 19
degree','surplus or shortage at 15 degree','surplus or shortage at 11
degree','surplus or shortage at 7 degree')
xlabel('Index of the months', 'FontSize',15);
ylabel('surplus or shortage for variuos tilt angle', 'FontSize',15);
```

```
figure
grid on
hold on
plot(dem-(dem-G(:,1)+abs(dem-G(:,1)))/2,'r', 'LineWidth',3)
plot(dem-(dem-G(:,5)+abs(dem-G(:,5)))/2,'c', 'LineWidth',3)
plot(dem-(dem-G(:,9)+abs(dem-G(:,9)))/2,'g', 'LineWidth',3)
plot(dem-(dem-G(:,13)+abs(dem-G(:,13)))/2,'b', 'LineWidth',3)
plot(dem-(dem-G(:,17)+abs(dem-G(:,17)))/2,'m', 'LineWidth',3)
legend('Demand met  at 23 degree','Demand met at 19 degree','Demand
met at 15 degree','Demand met at 11 degree','Demand met at 7 degree')
xlabel('Index of the months', 'FontSize',15);
ylabel('surplus or shortage for variuos tilt angle', 'FontSize',15);

figure
grid on
hold on
plot(dem,'k', 'LineWidth',5)
plot(G(:,1),'r', 'LineWidth',2)
plot(G(:,13),'b', 'LineWidth',2)
plot(dem-G(:,1),'r', 'LineWidth',3)
plot(dem-G(:,13),'b', 'LineWidth',3)
plot(dem-(dem-G(:,1)+abs(dem-G(:,1)))/2,'r', 'LineWidth',5)
plot(dem-(dem-G(:,13)+abs(dem-G(:,13)))/2,'b', 'LineWidth',5)
legend('Demand', 'generation at 23','generation at 12', 'surplus or
shortage at 23', 'surplus or shortage at 12', 'demand met at
23','demand met at 23')
xlabel('Index of the months', 'FontSize',15);
ylabel('Demand, generation, surplus/shortage and demand  met',
'FontSize',12);
```

C.3 Comparison of the result of 23^0 and 12^0 tilt angle

```
clear all
clf
DD=[ 4400 4400 5350 5250 5500 5800 6400 6000 5850 5400 4450 4150];
G_G23=[113 107 125 122 112 96 86 91 91 107 106 111];
G_G12=[101 99 122   124 118 102 92 94 91 101 95 97];
G_G=50*G_G23;
G_G1=50*G_G12;

len=[31 28 31 30 31 30 31 31 30 31 30 31];
format long g
r=.2
itta=80;
shortage=zeros(itta,1);
surplus=zeros(itta,1);

for k=1:itta
GG=k*G_G;
D=0;
G=0;
S=0;
```

```
      for j=1:12
            for i=1:len(j)
            D(j,i)=DD(j)*((1-r)+2*r*rand())/len(j);
            end
      end

      for j=1:12
            for i=1:len(j)
            G(j,i)=GG(j)*((1-r)+2*r*rand())/len(j);
      end
end

DEM(k)=sum(sum(D'));
GEN(k)=sum(sum(G'));
S=D-G;
S=S';
SS=sum(S);
shortage(k)=sum(SS+abs(SS))/2;
surplus(k)=sum(SS-abs(SS))/2;
end

surplus=abs(surplus);
diff=surplus-shortage;
diff=abs(diff);
pt=min(diff);
ptt=find(diff==pt);
demet=DEM'-shortage;
ff=sum(demet);
%figure
plot(DEM,'r', 'LineWidth',3)
hold on
grid on
plot(GEN,'k', 'LineWidth',3)
plot(demet,'g', 'LineWidth',3)
plot(shortage,'b', 'LineWidth',3)
plot(surplus,'m', 'LineWidth',3)
plot(diff,'y', 'LineWidth',3)
legend('Demand','Generation','Demand
met','Shortage','Surplus','Difference bet Shortage and surplus')
xlabel('Installed Capacity', 'FontSize',15);
ylabel('Shortage or Surplus', 'FontSize',15);
title('Installed Capacity VS Shortage or Surplus for Optimum
Size','FontSize',15);

ins_cap=ptt
ss=DD-ptt*G_G;
ss1=DD-ptt*G_G1;
disp('Yearly total demand')
sumdd=sum(DD)
disp('Yearly total Generation at 23 degree tilt angle')
sumgg=sum(ptt*G_G)
disp('Yearly total Generation at 12 degree tilt angle')
sumgg1=sum(ptt*G_G1)
```

```
disp('Yearly total shortage at 23 degree tilt angle')
srtgg=sum(abs(ss)+ss)/2
disp('Yearly total shortage at 12 degree tilt angle')
srtgg1=sum(abs(ss1)+ss1)/2

figure
plot(DD,'r', 'LineWidth',3)
hold on
grid on
plot(ptt*G_G,'y', 'LineWidth',3)
plot(ptt*G_G1,'g', 'LineWidth',3)
plot(ss,'y', 'LineWidth',3);
plot(ss1,'g', 'LineWidth',3);
xlabel('Months');
ylabel('Demand, Generation, Surplus or Shortage');

grid on
legend('Demand','Generation at 23 degree tilt angle', 'Generation at
12 degree tilt angle','Surplus/Shirtage at 23 degree tilt
angle','Surplus/Shirtage at 12 degree tilt angle')
```

C.4 Comparison of the Result of 23^0 and 12^0 Tilt Angle (Another Propgram)

```
clear all
clf
clc
format long g
y11=[2320.31 2308.32 2728.67 2849.11577 2917.83 2990.17 3161.45
3244.47 3083.4 3226.86 2502.36 2558.81];
y12=[2722.57 2717.84 3063.04 2881.46 3202.52 3307.1 3735.82 3677.42
3455.29 3226 2644.56 2589.76];
y13=[2645 2726.51 3501.76 3592.05 3600 3774.33 4080.22 3677.63 3725.15
3472.81 2923.01 2783.29];
yav=(y11+y12+y13)/3;
Y=[y11  y12  y13]
DD=[ 4400 4400 5350 5250 5500 5800 6400 6000 5850 5400 4450 4150];

ind={'January'  'February'  'March' 'April' 'May'   'June'  'July'
'August'    'September' 'October'   'November'  'December'}
%plot(a11,num2cell(ind))
plot(y11,'m', 'LineWidth',3)
hold on
grid on
plot(y12,'b', 'LineWidth',3)
plot(y13,'g', 'LineWidth',3)
plot(yav,'r', 'LineWidth',3)

legend('2011','2012','2013', 'Average')
xlabel('Index of month', 'FontSize',15);
xlim([1 12])
ylabel('Total Generation (GWh)', 'FontSize',15);
```

```
ylim([0 1.1*max(Y)])

figure
plot(DD,'g', 'LineWidth',3)
hold on
grid on
plot(yav,'r', 'LineWidth',3)
legend('Demand of the system in KWh', 'Average demand of Last three
years in GWh')
xlabel('Index of month', 'FontSize',15);
ylabel('Average Generation and Demand for a system', 'FontSize',14);
xlim([1 12])
ylim([0 1.1*max(DD)])

figure
plot(Y,'b', 'LineWidth',3)
hold on
grid on
legend('Demand of Last three years')
xlabel('Index of month', 'FontSize',15);
ylabel('Total Generation (GWh)', 'FontSize',15);
xlim([1 36])
ylim([0 1.1*max(Y)])

DD=[ 4400 4400 5350 5250 5500 5800 6400 6000 5850 5400 4450 4150];
G_G23=[113 107 125 122 112 96 86 91 91 107 106 111];
G_G12=[101 99 122 124   118 102 92 94 91 101 95 97];

G_G=50*G_G23;
G_G1=50*G_G12;

S23=DD-G_G;
S12=DD-G_G1;

figure
grid on
hold on
plot(DD,'r', 'LineWidth',3)
plot(G_G,'b', 'LineWidth',3)
plot(G_G1,'g', 'LineWidth',3)
plot(S23,'b', 'LineWidth',3)
plot(S12,'g', 'LineWidth',3)

legend('Demand of the system in KWh', 'Generation at 23 degree tilt',
'Generation at 12 degree tilt', 'surplus(-ve) /shortage(+ve) at 23
degree tilt','surplus(-ve) /shortage(+ve) at 23 degree tilt')
xlabel('Index of month', 'FontSize',15);
ylabel('Generation and Demand ', 'FontSize',15);
xlim([1 12])
%ylim([0 1.1*max(DD)])
```

C.5 More Analysis for generation and demand

```
clear all
clf
DD=[ 4400 4400 5350 5250 5500 5800 6400 6000 5850 5400 4450 4150];
G_G23=[113 107 125 122 112 96 86 91 91 107 106 111];
G40=40*[113 107 125 122 112 96 86 91 91 107 106 111];
G50=50*[113 107 125 122 112 96 86 91 91 107 106 111];
G60=60*[113 107 125 122 112 96 86 91 91 107 106 111];

S40=DD-G40;
S50=DD-G50;
S60=DD-G60;

% figure 1
bar(DD,'b')
hold on
grid on
xlabel('Index of months', 'FontSize',15);
ylabel('Demand in KWh','FontSize',15)
title('Demand for 200 family of a remote area(kWh)','FontSize',15)

% figure 2
figure
plot(DD,'r','LineWidth',3)
hold on
grid on
plot(G40,'b','LineWidth',3)
plot(S40,'b','LineWidth',2)
legend('Demand','Generation for 40kWp','Shortage(+ve) /Surplus(-ve)
for 40kWp')
xlabel('Index of months', 'FontSize',15);
ylabel('Demand, Generation, Shortage/Surplus(KWh)', 'FontSize',15);
title('Shortage or Surplus for 40kWp PV panel','FontSize',15);

% figure 3
figure
plot(DD,'r','LineWidth',3)
hold on
grid on
plot(G50,'b','LineWidth',3)
plot(S50,'b','LineWidth',2)
legend('Demand','Generation for 50kWp','Shortage(+ve) /Surplus(-ve)
for 40kWp')
xlabel('Index of months', 'FontSize',15);
ylabel('Demand, Generation, Shortage/Surplus(KWh)', 'FontSize',15);
title('Shortage or Surplus for 50kWp PV panel','FontSize',15);

% figure 4
figure
plot(DD,'r','LineWidth',3)
hold on
```

```
grid on
plot(G60,'b','LineWidth',3)
plot(S60,'b','LineWidth',2)
legend('Demand','Generation for 60kWp','Shortage(+ve) /Surplus(-ve)
for 40kWp')
xlabel('Index of months', 'FontSize',15);
ylabel('Demand, Generation, Shortage/Surplus(KWh)', 'FontSize',15);
title('Shortage or Surplus for 60kWp PV panel','FontSize',15);

% figure 5
figure
plot(DD,'r','LineWidth',3)
hold on
grid on
plot(G40,'b','LineWidth',3)
plot(G50,'g','LineWidth',3)
plot(G60,'y','LineWidth',3)
plot(S40,'b','LineWidth',2)
plot(S50,'g','LineWidth',2)
plot(S60,'y','LineWidth',2)
legend('Demand','Generation for 40kWp','Generation for
50kWp','Generation for 60kWp','Shortage/Surplus for
40kWp','Shortage/Surplus for 50kWp','Shortage/Surplus for 60kWp')
xlabel('Index of months', 'FontSize',15);
ylabel('Demand, Generation, Shortage/Surplus(KWh)', 'FontSize',15);
title('Shortage or Surplus for various sizes','FontSize',15);
```

APPENDIX-D
MATLAB Implementation Routine for the “Resource Optimizaiton”

D.1 Optimization Program Based on Various Parameter

```
clc; clear all
format short g; grid on
solar=[1 10 15 45 50];
wind=[0 1 2 5 10];
up_solar=70000; % unit price of Solar
up_wind=50000; %unit price of wind;
up_dg=20; k=0;
delete myfile.xls

for i=1:length(solar)
    for j=1:length(wind)
    k=k+1;
[s(k),w(k),T_D(k),T_s(k), T_w(k),
T_G(k),srt(k),srt_rat(k),srp(k),srp_rat(k),opti(k),dem_met(k),
uti(k),pen(k)]=opt(solar(i),wind(j));
      SL_NO(k)=k;
    Installation_cost(k)=up_solar*solar(i)+up_wind*wind(j);
    DG_cost(k)=up_dg*srt(k);

Total_cost_for_10_years_constant(k)=Installation_cost(k)+10*DG_cost(k)
;

Cost_of_energy(k)=Total_cost_for_10_years_constant(k)/(10*dem_met(k));
    end
end

P=[SL_NO;s;w;T_s;T_w;T_G;srt;srp;opti;Installation_cost;DG_cost;Total_
cost_for_10_years_constant;Cost_of_energy; dem_met;pen]';
Name={'SL No:','Solar PV','wind turbine','PV Generation','Wind
Generation','Combined generation','Shortage','Surplus','Optimum
shortage or surplus','Installation cost','Diesel Cost for 10
years','Total cost for 10 years while everythingis constant','Cost of
Energy pe KWh', 'Demand Met','penetraion'};
xlswrite('myfile.xls',[Name;num2cell(P)],'Sheet1');
for i=1:length(sum(P))
B(:,i)=P(:,i);%/max(P(:,i));
end

P9=arrange(B,9);
xlswrite('myfile.xls',[Name;num2cell(P9)],'Minimum shortage and
Surplus');
P10=arrange(B,10);
xlswrite('myfile.xls',[Name;num2cell(P10)],'Installation Cost');
P13=arrange(B,13);
xlswrite('myfile.xls',[Name;num2cell(P13)],'Energy Cost');
```

D.2 The „opt‟ Function used in Program D.1

```
function [i,j,total_demand,gen_sol, gen_wind, total_generation,
shortage,shortage_ratio,surplus,surplus_ratio,optimum,demand_met,utili
zation,penetration]=opt(a,b)
Demand=[ 4400 4400 5350 5250 5500 5800 6400 6000 5850 5400 4450 4150];
u_a=[113 107 125 122 112 96 86 91 91 107 106 111];%unit production of
a
u_b=[200 207 225 220 192 196 186 291 191 207 210 210];%unit production
of b
format short g;
Demand=(.92+0.1*rand())*[ 4400 4400 5350 5250 5500 5800 6400 6000 5850
5400 4450 4150];
u_a=(.92+0.1*rand())*[113 107 125 122 112 96 86 91 91 107 106
111];%unit production of a
u_b=(.92+0.1*rand())*[200 207 225 220 192 196 186 191 191 207 210
210];%unit production of b

%a=5 ; %b=30
t_a=a*u_a; %Total production of a
t_b=b*u_b; %Total production of b
t_g=t_a+t_b; %%total production of a and b
diff=t_g-Demand;
shortage=(abs(diff)-diff)/2;
surplus=(abs(diff)+diff)/2;
util=Demand-shortage;

i=a;
j=b;
total_demand=sum(Demand);
gen_sol=sum(t_a);
gen_wind=sum(t_b);
total_generation=sum(t_g);
shortage=sum(shortage);
shortage_ratio=shortage/sum(t_g);
surplus=sum(surplus);
surplus_ratio=surplus/sum(t_g);
optimum=surplus-shortage;
demand_met=sum(util);
utilization=sum(util)/total_generation;
penetration=sum(util)/total_demand;
end
```

D.3 The "arrange" Function Used in Program D.1

```
function [C]=arrange(A,i)

format short g;
b=A(:,i);
c=sort(b);
k=0;
temp=0;
i=1;
while (i<=length(b))
  temp=find(c(i)==b);
  i=i+length(temp) ;
  k=[k;temp];

end
k=k(2:end,:) ;
for i=1:length(k)
    C(i,:)=A(k(i),:);
end
end
```

D.4 A similar program of D.1 but this program deals with more parameter than D.1

```
%arrange function has been added
clc
clear all
format short g
grid on
%solar=5;%1:50;
solar=[1 10 15];
%wind=25%;1:40
wind=[0 5 10];
biogas= [3 8 12];
up_solar=70000; % unit price of Solar
up_wind=50000; %unit price of wind;
up_bio=20000;
up_dg=20;
k=0;
%delete myfile.xls

for i=1:length(solar)
    for j=1:length(wind)
        for  p=1:length(biogas)

    k=k+1;
    [s(k),w(k),b(k),T_D(k),T_s(k), T_w(k),T_b(k),
T_G(k),srt(k),srt_rat(k),srp(k),srp_rat(k),opti(k),dem_met(k),
uti(k),pen(k)]=optimization_3_parameter(solar(i),wind(j), biogas(p));
    SL_NO(k)=k;

Installation_cost(k)=up_solar*solar(i)+up_wind*wind(j)+up_bio*biogas(p
);
```

```
    DG_cost(k)=up_dg*srt(k);


Total_cost_for_10_years_constant(k)=Installation_cost(k)+10*DG_cost(k)
;

Cost_of_energy(k)=Total_cost_for_10_years_constant(k)/(10*dem_met(k));
         end
     end
end

P=[SL_NO;s;w;b; T_s;T_w;T_b;T_G; srt;DG_cost;srp;dem_met;
pen;Installation_cost;Cost_of_energy
;Total_cost_for_10_years_constant]';
Name={'SL No:','Solar PV','Wind Turbine', 'Biogas','PV
Generation','Wind Generation','Biogas Generation','Combined Total
Generation','Shortage met by Diesel Generator','Yearly Diesel
Cost','Surplus',  'Demand Met','penetraion','Installation cost','Cost
of Energy pe KWh','Total cost for 10 years'}

xlswrite('myfile.xls',[Name;num2cell(P)],'Sheet1');

for i=1:length(sum(P))
B(:,i)=P(:,i);%/max(P(:,i));
end

P12=arrange(B,12);
xlswrite('myfile.xls',[Name;num2cell(P12)],'Demand Met');
P13=arrange(B,13);
xlswrite('myfile.xls',[Name;num2cell(P13)],'Penetration');
P14=arrange(B,14);
xlswrite('myfile.xls',[Name;num2cell(P14)],'Installation Cost');
P15=arrange(B,15);
xlswrite('myfile.xls',[Name;num2cell(P15)],'Energy Cost');
```

D.5 The function “optimization_3_parameter” used in D.4

```
function [i,j,k,total_demand,gen_solar, gen_wind,gen_biogas,
total_generation,
shortage,shortage_ratio,surplus,surplus_ratio,optimum,demand_met,utili
zation,penetration]=optimization_3_parameter(a,b,c)

Demand=[ 4400 4400 5350 5250 5500 5800 6400 6000 5850 5400 4450 4150];
%u_a=[113 107 125 122 112 96 86 91 91 107 106 111];%unit production of
a
G_G12=[101 99 122   124 118 102 92 94 91 101 95 97];
u_a=G_G12;
u_b=[200 207 225 220 192 196 186 291 191 207 210 210];%unit production
of b
u_c=[160 180 170 175 165 160 165 160 155 150 155 160];%unit production
of c
format short g;
```

```
Demand=(1+0.0*rand())*[ 4400 4400 5350 5250 5500 5800 6400 6000 5850
5400 4450 4150];
t_a=a*u_a %Total production of a
t_b=b*u_b %Total production of b
t_c=c*u_c %Total production of b
t_g=t_a+t_b+t_c %%total production of a and b and c
diff=t_g-Demand
shortage=(abs(diff)-diff)/2
surplus=(abs(diff)+diff)/2
util=Demand-shortage;

i=a; %1
j=b; %2
k=c; %3

total_demand=sum(Demand); %4
gen_solar=sum(t_a); %5
gen_wind=sum(t_b); %6
gen_biogas=sum(t_c); %7
total_generation=sum(t_g);% 8
shortage=sum(shortage); %9
shortage_ratio=shortage/sum(t_g); % 10
surplus=sum(surplus); %11
surplus_ratio=surplus/sum(t_g); % 12
optimum=surplus-shortage;    %13
demand_met=sum(util);   %14
utilization=sum(util)/total_generation; %15
penetration=sum(util)/total_demand; %16
end
```

APPENDIX-E

Results of Solar, Biogas, Wind Diesel Hybrid System Analysis

The output															
SL No:	Solar PV	Wind Turbine	Biogas	PV Generation	Wind Generation	Biogas Generation	Combined Total Generation	Shortage met by Diesel Generator	Yearly Diesel Cost	Surplus	Demand Met	Penetration	Installation cost	Cost of Energy pe KWh	Total cost for 10 years
1	1	0	3	1236	0	5865	7101	55849	1116980	0	7101	0.112804	130000	159.1297	11299800
2	1	0	8	1236	0	15640	16876	46074	921480	0	16876	0.268086	230000	55.96587	9444800
3	1	0	12	1236	0	23460	24696	38254	765080	0	24696	0.392311	310000	32.23518	7960800
4	1	5	3	1236	12675	5865	19776	43174	863480	0	19776	0.314154	380000	45.58455	9014800
5	1	5	8	1236	12675	15640	29551	33399	667980	0	29551	0.469436	480000	24.22862	7159800
6	1	5	12	1236	12675	23460	37371	25579	511580	0	37371	0.593662	560000	15.18771	5675800
7	1	10	3	1236	25350	5865	32451	30499	609980	0	32451	0.515504	630000	20.73834	6729800
8	1	10	8	1236	25350	15640	42226	20724	414480	0	42226	0.670786	730000	11.54455	4874800
9	1	10	12	1236	25350	23460	50046	12904	258080	0	50046	0.795012	810000	6.775367	3390800
10	10	0	3	12360	0	5865	18225	44725	894500	0	18225	0.289515	760000	53.25103	9705000
11	10	0	8	12360	0	15640	28000	34950	699000	0	28000	0.444797	860000	28.03571	7850000
12	10	0	12	12360	0	23460	35820	27130	542600	0	35820	0.569023	940000	17.77219	6366000
13	10	5	3	12360	12675	5865	30900	32050	641000	0	30900	0.490866	1010000	24.01294	7420000
14	10	5	8	12360	12675	15640	40675	22275	445500	0	40675	0.646148	1110000	13.68162	5565000
15	10	5	12	12360	12675	23460	48495	14455	289100	0	48495	0.770373	1190000	8.415301	4081000
16	10	10	3	12360	25350	5865	43575	19375	387500	0	43575	0.692216	1260000	11.78428	5135000
17	10	10	8	12360	25350	15640	53350	9900	198000	300	53050	0.842732	1360000	6.295947	3340000
18	10	10	12	12360	25350	23460	61170	4880	97600	3100	58070	0.922478	1440000	4.160496	2416000
19	15	0	3	18540	0	5865	24405	38545	770900	0	24405	0.387689	1110000	36.13604	8819000
20	15	0	8	18540	0	15640	34180	28770	575400	0	34180	0.542971	1210000	20.37449	6964000
21	15	0	12	18540	0	23460	42000	20950	419000	0	42000	0.667196	1290000	13.04762	5480000
22	15	5	3	18540	12675	5865	37080	25870	517400	0	37080	0.589039	1360000	17.62136	6534000
27	15	10	12	18540	25350	23460	67350	2300	46000	6700	60650	0.963463	1790000	3.70981	2250000

Optimization according to Demand Met

SL No:	Solar PV	Wind Turbine	Bio gas	PV Generation	Wind Generation	Biogas Generation	Combined Total Generation	Shortage met by Diesel Generator	Yearly Diesel Cost	Surplus	**Demand Met**	Penetration	Installation cost	Cost of Energy pe KWh	Total cost for 10 years
1	1	0	3	1236	0	5865	7101	55849	1116980	0	**7101**	0.112804	130000	159.1297	11299800
2	1	0	8	1236	0	15640	16876	46074	921480	0	**16876**	0.268086	230000	55.96587	9444800
10	10	0	3	12360	0	5865	18225	44725	894500	0	**18225**	0.289515	760000	53.25103	9705000
4	1	5	3	1236	12675	5865	19776	43174	863480	0	**19776**	0.314154	380000	45.58455	9014800
19	15	0	3	18540	0	5865	24405	38545	770900	0	**24405**	0.387689	1110000	36.13604	8819000
3	1	0	12	1236	0	23460	24696	38254	765080	0	**24696**	0.392311	310000	32.23518	7960800
11	10	0	8	12360	0	15640	28000	34950	699000	0	**28000**	0.444797	860000	28.03571	7850000
5	1	5	8	1236	12675	15640	29551	33399	667980	0	**29551**	0.469436	480000	24.22862	7159800
13	10	5	3	12360	12675	5865	30900	32050	641000	0	**30900**	0.490866	1010000	24.01294	7420000
7	1	10	3	1236	25350	5865	32451	30499	609980	0	**32451**	0.515504	630000	20.73834	6729800
20	15	0	8	18540	0	15640	34180	28770	575400	0	**34180**	0.542971	1210000	20.37449	6964000
12	10	0	12	12360	0	23460	35820	27130	542600	0	**35820**	0.569023	940000	17.77219	6366000
22	15	5	3	18540	12675	5865	37080	25870	517400	0	**37080**	0.589039	1360000	17.62136	6534000
6	1	5	12	1236	12675	23460	37371	25579	511580	0	**37371**	0.593662	560000	15.18771	5675800
14	10	5	8	12360	12675	15640	40675	22275	445500	0	**40675**	0.646148	1110000	13.68162	5565000
21	15	0	12	18540	0	23460	42000	20950	419000	0	**42000**	0.667196	1290000	13.04762	5480000
8	1	10	8	1236	25350	15640	42226	20724	414480	0	**42226**	0.670786	730000	11.54455	4874800
16	10	10	3	12360	25350	5865	43575	19375	387500	0	**43575**	0.692216	1260000	11.78428	5135000
23	15	5	8	18540	12675	15640	46855	16095	321900	0	**46855**	0.744321	1460000	9.986127	4679000
15	10	5	12	12360	12675	23460	48495	14455	289100	0	**48495**	0.770373	1190000	8.415301	4081000
25	15	10	3	18540	25350	5865	49755	13195	263900	0	**49755**	0.790389	1610000	8.539845	4249000
9	1	10	12	1236	25350	23460	50046	12904	258080	0	**50046**	0.795012	810000	6.775367	3390800
17	10	10	8	12360	25350	15640	53350	9900	198000	300	**53050**	0.842732	1360000	6.295947	3340000
24	15	5	12	18540	12675	23460	54675	8865	177300	590	**54085**	0.859174	1540000	6.125543	3313000

Optimization according to Penetration

SL No:	Solar PV	Wind Turbine	Bio gas	PV Generation	Wind Generation	Biogas Generation	Combined Total Generation	Shortage met by Diesel Generator	Yearly Diesel Cost	Surplus	Demand Met	**Penetration**	Installation cost	Cost of Energy pe KWh	Total cost for 10 years
1	1	0	3	1236	0	5865	7101	55849	1116980	0	7101	**0.112804**	130000	159.1297	11299800
2	1	0	8	1236	0	15640	16876	46074	921480	0	16876	**0.268086**	230000	55.96587	9444800
10	10	0	3	12360	0	5865	18225	44725	894500	0	18225	**0.289515**	760000	53.25103	9705000
4	1	5	3	1236	12675	5865	19776	43174	863480	0	19776	**0.314154**	380000	45.58455	9014800
19	15	0	3	18540	0	5865	24405	38545	770900	0	24405	**0.387689**	1110000	36.13604	8819000
3	1	0	12	1236	0	23460	24696	38254	765080	0	24696	**0.392311**	310000	32.23518	7960800
11	10	0	8	12360	0	15640	28000	34950	699000	0	28000	**0.444797**	860000	28.03571	7850000
5	1	5	8	1236	12675	15640	29551	33399	667980	0	29551	**0.469436**	480000	24.22862	7159800
13	10	5	3	12360	12675	5865	30900	32050	641000	0	30900	**0.490866**	1010000	24.01294	7420000
7	1	10	3	1236	25350	5865	32451	30499	609980	0	32451	**0.515504**	630000	20.73834	6729800
20	15	0	8	18540	0	15640	34180	28770	575400	0	34180	**0.542971**	1210000	20.37449	6964000
12	10	0	12	12360	0	23460	35820	27130	542600	0	35820	**0.569023**	940000	17.77219	6366000
22	15	5	3	18540	12675	5865	37080	25870	517400	0	37080	**0.589039**	1360000	17.62136	6534000
6	1	5	12	1236	12675	23460	37371	25579	511580	0	37371	**0.593662**	560000	15.18771	5675800
14	10	5	8	12360	12675	15640	40675	22275	445500	0	40675	**0.646148**	1110000	13.68162	5565000
21	15	0	12	18540	0	23460	42000	20950	419000	0	42000	**0.667196**	1290000	13.04762	5480000
8	1	10	8	1236	25350	15640	42226	20724	414480	0	42226	**0.670786**	730000	11.54455	4874800
16	10	10	3	12360	25350	5865	43575	19375	387500	0	43575	**0.692216**	1260000	11.78428	5135000
23	15	5	8	18540	12675	15640	46855	16095	321900	0	46855	**0.744321**	1460000	9.986127	4679000
15	10	5	12	12360	12675	23460	48495	14455	289100	0	48495	**0.770373**	1190000	8.415301	4081000
25	15	10	3	18540	25350	5865	49755	13195	263900	0	49755	**0.790389**	1610000	8.539845	4249000
9	1	10	12	1236	25350	23460	50046	12904	258080	0	50046	**0.795012**	810000	6.775367	3390800
17	10	10	8	12360	25350	15640	53350	9900	198000	300	53050	**0.842732**	1360000	6.295947	3340000
24	15	5	12	18540	12675	23460	54675	8865	177300	590	54085	**0.859174**	1540000	6.125543	3313000

Optimization according to Installation Cost

SL No:	Solar PV	Wind Turbine	Bio gas	PV Generation	Wind Generation	Biogas Generation	Combined Total Generation	Shortage met by Diesel Generator	Yearly Diesel Cost	Surplus	Demand Met	Penetration	**Installation cost**	Cost of Energy pe KWh	Total cost for 10 years
1	1	0	3	1236	0	5865	7101	55849	1116980	0	7101	0.112804	**130000**	159.1297	11299800
2	1	0	8	1236	0	15640	16876	46074	921480	0	16876	0.268086	**230000**	55.96587	9444800
3	1	0	12	1236	0	23460	24696	38254	765080	0	24696	0.392311	**310000**	32.23518	7960800
4	1	5	3	1236	12675	5865	19776	43174	863480	0	19776	0.314154	**380000**	45.58455	9014800
5	1	5	8	1236	12675	15640	29551	33399	667980	0	29551	0.469436	**480000**	24.22862	7159800
6	1	5	12	1236	12675	23460	37371	25579	511580	0	37371	0.593662	**560000**	15.18771	5675800
7	1	10	3	1236	25350	5865	32451	30499	609980	0	32451	0.515504	**630000**	20.73834	6729800
8	1	10	8	1236	25350	15640	42226	20724	414480	0	42226	0.670786	**730000**	11.54455	4874800
10	10	0	3	12360	0	5865	18225	44725	894500	0	18225	0.289515	**760000**	53.25103	9705000
9	1	10	12	1236	25350	23460	50046	12904	258080	0	50046	0.795012	**810000**	6.775367	3390800
11	10	0	8	12360	0	15640	28000	34950	699000	0	28000	0.444797	**860000**	28.03571	7850000
12	10	0	12	12360	0	23460	35820	27130	542600	0	35820	0.569023	**940000**	17.77219	6366000
13	10	5	3	12360	12675	5865	30900	32050	641000	0	30900	0.490866	**1010000**	24.01294	7420000
14	10	5	8	12360	12675	15640	40675	22275	445500	0	40675	0.646148	**1110000**	13.68162	5565000
19	15	0	3	18540	0	5865	24405	38545	770900	0	24405	0.387689	**1110000**	36.13604	8819000
15	10	5	12	12360	12675	23460	48495	14455	289100	0	48495	0.770373	**1190000**	8.415301	4081000
20	15	0	8	18540	0	15640	34180	28770	575400	0	34180	0.542971	**1210000**	20.37449	6964000
16	10	10	3	12360	25350	5865	43575	19375	387500	0	43575	0.692216	**1260000**	11.78428	5135000
21	15	0	12	18540	0	23460	42000	20950	419000	0	42000	0.667196	**1290000**	13.04762	5480000
17	10	10	8	12360	25350	15640	53350	9900	198000	300	53050	0.842732	**1360000**	6.295947	3340000
22	15	5	3	18540	12675	5865	37080	25870	517400	0	37080	0.589039	**1360000**	17.62136	6534000
18	10	10	12	12360	25350	23460	61170	4880	97600	3100	58070	0.922478	**1440000**	4.160496	2416000
23	15	5	8	18540	12675	15640	46855	16095	321900	0	46855	0.744321	**1460000**	9.986127	4679000
24	15	5	12	18540	12675	23460	54675	8865	177300	590	54085	0.859174	**1540000**	6.125543	3313000

Optimization according to Cost of Energy

SL No:	Solar PV	Wind Turbine	Bio gas	PV Generation	Wind Generation	Biogas Generation	Combined Total Generation	Shortage met by Diesel Generator	Yearly Diesel Cost	Surplus	Demand Met	Penetration	Installation cost	**Cost of Energy pe KWh**	Total cost for 10 years
27	15	10	12	18540	25350	23460	67350	2300	46000	6700	60650	0.963463	1790000	**3.70981**	2250000
18	10	10	12	12360	25350	23460	61170	4880	97600	3100	58070	0.922478	1440000	**4.160496**	2416000
26	15	10	8	18540	25350	15640	59530	5710	114200	2290	57240	0.909293	1710000	**4.98253**	2852000
24	15	5	12	18540	12675	23460	54675	8865	177300	590	54085	0.859174	1540000	**6.125543**	3313000
17	10	10	8	12360	25350	15640	53350	9900	198000	300	53050	0.842732	1360000	**6.295947**	3340000
9	1	10	12	1236	25350	23460	50046	12904	258080	0	50046	0.795012	810000	**6.775367**	3390800
15	10	5	12	12360	12675	23460	48495	14455	289100	0	48495	0.770373	1190000	**8.415301**	4081000
25	15	10	3	18540	25350	5865	49755	13195	263900	0	49755	0.790389	1610000	**8.539845**	4249000
23	15	5	8	18540	12675	15640	46855	16095	321900	0	46855	0.744321	1460000	**9.986127**	4679000
8	1	10	8	1236	25350	15640	42226	20724	414480	0	42226	0.670786	730000	**11.54455**	4874800
16	10	10	3	12360	25350	5865	43575	19375	387500	0	43575	0.692216	1260000	**11.78428**	5135000
21	15	0	12	18540	0	23460	42000	20950	419000	0	42000	0.667196	1290000	**13.04762**	5480000
14	10	5	8	12360	12675	15640	40675	22275	445500	0	40675	0.646148	1110000	**13.68162**	5565000
6	1	5	12	1236	12675	23460	37371	25579	511580	0	37371	0.593662	560000	**15.18771**	5675800
22	15	5	3	18540	12675	5865	37080	25870	517400	0	37080	0.589039	1360000	**17.62136**	6534000
12	10	0	12	12360	0	23460	35820	27130	542600	0	35820	0.569023	940000	**17.77219**	6366000
20	15	0	8	18540	0	15640	34180	28770	575400	0	34180	0.542971	1210000	**20.37449**	6964000
7	1	10	3	1236	25350	5865	32451	30499	609980	0	32451	0.515504	630000	**20.73834**	6729800
13	10	5	3	12360	12675	5865	30900	32050	641000	0	30900	0.490866	1010000	**24.01294**	7420000
5	1	5	8	1236	12675	15640	29551	33399	667980	0	29551	0.469436	480000	**24.22862**	7159800
11	10	0	8	12360	0	15640	28000	34950	699000	0	28000	0.444797	860000	**28.03571**	7850000
3	1	0	12	1236	0	23460	24696	38254	765080	0	24696	0.392311	310000	**32.23518**	7960800
19	15	0	3	18540	0	5865	24405	38545	770900	0	24405	0.387689	1110000	**36.13604**	8819000
4	1	5	3	1236	12675	5865	19776	43174	863480	0	19776	0.314154	380000	**45.58455**	9014800

APPENDIX-F

Determination of Maximum Voltage between Two Isolated Microgrids when Interconnected”

F.1 Program for “voltage_drop.m”

```
clear all
len=100:50:1000
format long
r=230^2/(10000/0.8);
Zload= r*(0.8+0.6i)

for k=1:length(len)
      R=0.0017719*len(k);
      L=len(k)*1e-7*(1+4*log(50/1)) %% 1000 is for 1KM
      C=len(k)*pi*8.854e-12/(log(50/1))%% 1000 is for 1KM
      XL=i*2*pi*50*L
      XC=1/(i*2*pi*50*C)
      Ztemp=1/((1/XC)+(1/Zload))
      Zline=R+XL
      Ztotal=Zline+Ztemp
      Current=230/Ztotal
      Voltage(k)=abs(Ztemp*Current)
      drop(k)=abs(Zline*Current)
end

plot(len,drop,'y', 'LineWidth',3)
hold on
plot(len,Voltage,'r', 'LineWidth',3)
grid on

legend('Voltage Drop in Interconnection line','VOltage at Node 2')
xlabel('Distance of Node 2 from Node 1', 'FontSize',13);
ylabel('Voltage', 'FontSize',13);
title('Distance Vs Voltage drop and Voltage at Node 2')
```

APPENDIX-G

Determination of Maximum Voltage between Two Isolated Microgrids When Interconnected”

G.1 Policy01.m

```
clear all
clc
clf

% In this program, it is assumed that entity 1 will install 10KWp of
% solar PV and 45 unit of entity 2 type CPU (each having 2KWp) will
% provide 90KWp of solar PV. Thus a total of 100KWp Solar PV. The battery
% backup for the complete system will be provided by the entity 1



Buy_price= 10;% price of buy per unit of energy(per KWh) from entity 2, it is changed manually for each iteration
Sale_price=35;% price of sale per unit of energy(per KWh) to entity 2, it is changed manually for each iteration as 20, 25, 30 and 35

for i=Buy_price:Sale_price-1


Usable_energy=1300; % KWh per year

Panel_2=2; % in KWp, 2KWp is assumed as the unit installtion size of each CPU
Panel_Price_unit=60000;% per KWp
Panel_price_total=Panel_2*Panel_Price_unit;

CPU_cost= 20000; % per KWp and others
CPU_cost_total= Panel_2*CPU_cost;
Total_investment=Panel_price_total+CPU_cost_total;

Running_cost=0.02*Total_investment; %   2% of initial investment
Energy=Usable_energy*Panel_2;
Revenue=Energy*i;
Net_Profit= Revenue-Running_cost;
return_2=Total_investment/Net_Profit; % payback period for entity 2

Panel_1=10; %10 KWp is assumed to be the size of authority 1 power source
Panel=Panel_1*1000*60; %60,000 per KWp
Battery = 4800000; % For 10KWp Authority 1 + 90 KWp from authority 2
```

```
Distribution_System= 5*80000;  % 5km and 80,000 for each km
%Pole   55
Diesel_generator=3*200000;  %10KW  Generator, no 3

Others=10*10000; % 10,000 per KWp
connection_charge= 200*5000; % 5000 BDT per connection
Initial_cost= Panel+ Battery+ Distribution_System+ Diesel_generator+
Others - connection_charge; %65,00,000

Energy_1= Usable_energy*Panel_1; % 10KWp comes from entity 1
Energy_2= Usable_energy*Panel_2*45; % 45 number of CPU, each have 2KWp
solar panel = 90KWp from entity 2
Energy_panel= Energy_1+Energy_2;
Energy_loss=Energy_panel*0.04; % loss due to battery charging and
discharging
Energy_panel_use=Energy_panel-Energy_loss;
Energy_DG= 0.3*Energy_panel_use/0.7; % Assume 30% of Total energy comes
from DG
Energy_sale=Energy_panel_use+Energy_DG;
Energy_sale_price=Energy_sale*Sale_price;

Energy_2_cost=Energy_2*i; % total cost to buy energy from entity 2
Energy_DG_cost=Energy_DG*15; % Assumed to be same as Sandwip DG cost
Yearly_Running_Cost= 400000;  %  Sandwip  employee + other maintenance
cost

Yearly_cost=Energy_2_cost+  Energy_DG_cost + Yearly_Running_Cost; %

Yearly_profit=Energy_sale_price-Yearly_cost;
return_1=Initial_cost/Yearly_profit;
R_1(i)=return_1;
R_2(i)=return_2;
diff(i)=return_1-return_2;
end

plot(R_1,'r', 'LineWidth', 3)
hold on
grid on
plot(R_2,'LineWidth', 3)
xlim([22, 28]) % this limit is changed in each iteration for better view
of produced image

legend('Entity 1','Entity 2')
xlabel('Buying Price of energy from entity 2  in BDT', 'FontSize',12);
ylabel('Simple Payback period in Years', 'FontSize',12);
```

G.2 Policy02.m

```
clear all
clc
clf

% In this program, it is assumed that entity 1 will install 10KWp of
% solar PV and 45 unit of entity 2 type CPU (each having 2KWp) will
% provide 90KWp of solar PV. Thus a total of 100KWp Solar PV. The battery
% backup for the complete system will be provided by the entity 1



Buy_price= 25;% price of buy per unit of energy(per KWh) from entity 2,
it is changed manually for each iteration  as 10, 15, 20, 25
Sale_price=40;% price of sale per unit of energy(per KWh) to entity 2, it
is changed manually for each iteration

for i=Buy_price+1:Sale_price
        Usable_energy=1300; % KWh per year
        Panel_2=2; % in KWp, 2KWp is assumed as the unit installtion size
of each CPU
        Panel_Price_unit=60000;% per KWp
        Panel_price_total=Panel_2*Panel_Price_unit;
        CPU_cost= 20000; % per KWp and others
        CPU_cost_total= Panel_2*CPU_cost;
        Total_investment=Panel_price_total+CPU_cost_total;
        Running_cost=0.02*Total_investment; %   2% of initial investment
        Energy=Usable_energy*Panel_2;

Revenue=Energy*Buy_price;
Net_Profit= Revenue-Running_cost;
return_2=Total_investment/Net_Profit; % payback period for entity 2



        Panel_1=10; %10 KWp is assumed to be the size of authority 1
power source
        Panel=Panel_1*1000*60; %60,000 per KWp
        Battery = 4800000; % For 10KWp Authority 1 + 90 KWp from
authority 2
        Distribution_System= 5*80000;  % 5km and 80,000 for each km
        %Pole   55
        Diesel_generator=3*200000;  %10KW  Generator, no 3
        Others=10*10000; % 10,000 per KWp
        connection_charge= 200*5000; % 5000 BDT per connection
        Initial_cost= Panel+ Battery+ Distribution_System+
Diesel_generator+ Others - connection_charge; %65,00,000

        Energy_1= Usable_energy*Panel_1; % 10KWp comes from entity 1
```

```
        Energy_2= Usable_energy*Panel_2*45; % 45 number of CPU, each have
2KWp solar panel = 90KWp from entity 2
        Energy_panel= Energy_1+Energy_2;
        Energy_loss=Energy_panel*0.04; % loss due to battery charging and
discharging
        Energy_panel_use=Energy_panel-Energy_loss;
        Energy_DG= 0.3*Energy_panel_use/0.7; % Assume 30% of Total energy
comes from DG
        Energy_sale=Energy_panel_use+Energy_DG;
        Energy_2_cost=Energy_2*Buy_price; % total cost to buy energy from
entity 2
        Energy_DG_cost=Energy_DG*15; % Assumed to be same as Sandwip DG
cost
        Yearly_Running_Cost= 400000;  %  Sandwip  employee + other
maintenance cost
        Yearly_cost=Energy_2_cost+  Energy_DG_cost + Yearly_Running_Cost;
%

      Energy_sale_price=Energy_sale*i;
      Yearly_profit=Energy_sale_price-Yearly_cost;
      return_1=Initial_cost/Yearly_profit;
      R_1(i)=return_1;
      R_2(i)=return_2;
      diff(i)=return_1-return_2;
end

plot(R_1,'r', 'LineWidth', 3)
hold on
grid on
plot(R_2,'LineWidth', 3)
xlim([33, 37]) % this limit is changed in each iteration for better view
of produced image

legend('Entity 1','Entity 2')
xlabel('Price of sales of energy by entity 1  in BDT', 'FontSize',12);
ylabel('Simple Payback period in Years', 'FontSize',12);
```

APPENDIX-H
Projection about the Installed Capacity

H.1 time_projection.m

```
clc
clear all
n=1
m=20
acs=2; %avgerage CPU Size in KW
year=n:m;
%%% idcol is the number of instllation
idcol=[772 15745 36380 63959 101110 170672 285773 455689 780756 1254923
1700000 2700000 4288235.294 6810726.644 10817036.43 17179999.04
27285880.83 43336398.97 68828398.36 109315691.5 173619039.5 275747886.2
437952525.2 695571657.6 1104731456];
cip=acs*idcol(:,n:m);

pro_200= 2*cip/1000;
pro_150= 1.5*cip/1000;
pro_100= cip/1000;
pro_90= 0.9*cip/1000;
pro_80= 0.8*cip/1000;
pro_70= 0.7*cip/1000;
pro_50= 0.5*cip/1000;

pro= round([pro_200(m) pro_150(m) pro_100(m) pro_80(m) pro_50(m)])

h=figure
plot(year,pro_200,'r', 'LineWidth',3)
hold on
grid on
plot(year,pro_150,'y', 'LineWidth',3)
plot(year,pro_100,'c', 'LineWidth',3)
plot(year,pro_90,'m', 'LineWidth',3)
plot(year,pro_80,'b', 'LineWidth',3)
plot(year,pro_70,'g', 'LineWidth',3)
plot(year,pro_50,'k', 'LineWidth',3)

legend('200% rate of SHS','150% rate of SHS','100% rate of SHS','90% rate
of SHS','80% rate of SHS','70% rate of SHS','50% rate of
SHS','Location','Best')
xlabel('Year after program start', 'FontSize',13);
ylabel('Forcasted installed capacity MWp', 'FontSize',13);
title('10-20 years projection')
%saveas(h,'1-5 years projection','jpg')
```