



Design, Planning, and Modelling of Renewable Energy Integrated Microgrid for Rural Electrification in Bangladesh

By

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Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including concepts, modeling of software based simulations, and results. The simulation models have attached in the CD are virus and error free. Where information has derived other sources, I confirm that this has been included in the thesis.

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মা তোমাকে অনেক অনেক ধন্যবাদ, তোমার দোয়া, আশির্বাদ আমাকে সবসময় সামনে চলতে কতটা সহায়তা করে সেটা হয়ত কখন বলা হবে না, তোমার অনুপ্রেরণা এবং উৎসাহ আমাকে সব সময় সামনে চলতে প্রেরণা যোগায়



Abstract

Electric power crisis is one of the major problem in Bangladesh, day by day the gap between demand and generation is increasing. Moreover, most of the power plants are gas based which will be phased out in future. An alternate electric supply is an essential part for electrifying the developing countries, in this context an innovative approach of rural electrification including DC microgrid, mini-grid and nanogrid would be technically and economically feasible. The thesis also attention on the development of technology which enables community owned power system to emerge in the rural areas based on distributed SHS and demand of that community.

Firstly, the electric status and renewable potential in Bangladesh studied and considered those data into the software based simulation to analysis the technical feasibility to implement DC microgrid by Homer pro tools. The distributed RES (Renewable Energy sources) considered solar PV and biomass. The booming of a large number of individual SHS (Solar Home System) in Bangladesh, bottom-up energy sharing concept would have studied to configure the optimal design of microgrid system and different configuration including grid connected and DC and AC system studied.

Secondly, The PV module is highly dependent on cell temperature and solar irradiance, the ambient temperature, and solar irradiance mathematical equation have considered to model and simulate in MATLAB/SIMULINK based environment. Similarly charge controller, battery operation, and performance analysis with respect to the PV model. In the distributed energy sources are mainly SHS including large size and regular also model and simulate in MATLAB/SIMULINK software. For instance, the thesis mainly focuses on an optimal design, planning, sizing of DC hybrid microgrid, the SHS, and biomass-based power system with the goal of maximizing the efficiency and reliability. Homer Pro tool used in the work for design an optimal configuration and sizing for technical feasibility.

Finally, a model of DC microgrid compresses with micro sources like SHS systems, μ -CHP, the household loads model in MATLAB/SIMULINK. Decentralized SHS control strategies (droop control) and operation also design and model in MATLAB/SIMULINK environment, where DC - DC converter needs to couple SHS and DC microgrid.

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List of Abbreviations

Organizational, Institutional and Economical Acronyms

ADB	Asian Development Bank
BPDB	Bangladesh Power Development Board
BREB	Bangladesh Rural Electrification Board
IDCOL	Infrastructure Development Company Limited
DESCO	Dhaka Electric Supply Company
DESA	Dhaka Electric Supply Authority
EIA	Energy Information Administration
FY	Fiscal Year
IEG	Independent Evaluation Group
IEA	International Energy Agency
IPPs	Independent Power Producers
GOB	Government of Bangladesh
MDG	Millennium Development Goal
NPC	Net Present Cost
PGCB	Power Grid Company of Bangladesh
PBS	Palli Bidyut Samity
REB	Rural Electrification Board
SREDA	Sustainable and Renewable Energy Development Authority
UNDP	United Nation Development Program
WZPDC	West Zone Power Distribution Company

Technical and Scientific Acronyms

AC	Alternating Current
Ah	Ampere Hour
ARV	Array Reconnect Voltage
BHS	Battery Home System
CHP	Combined Heat and Pressure
CCHP	Combined Cooling Heat and Pressure
CFL	Compact Fluorescent Lamp
CBES	Community Based Energy Storage
CR	Charge Regulator
COP	Coefficient of Performance
EEF	Energy Efficiency Factor
EMS	Energy Management System
ESS	Energy Storage System
DSS	Distributed Storage System
DGS	Distributed Generation System
DER	Distributed Energy Resources
DOC	Depth of Discharge
DOD	Depth of Discharge
DC	Direct Current
FF	Fill Factor
HVD	High Voltage Disconnect
I_{Ph}	Photo Current
I_d	Diode Current
I_{sc}	Short Circuit Current
I_{MPP}	Maximum Power Point Current
kW	Kilo Watt
kWh	Kilo Watt Hour
LVD	Load Disconnect Voltage
LVR	Load Reconnect Voltage

NG	Nano Grid
MT	Micro Turbine
MG	Micro Grid
MPPT	Maximum Power Point Tracker
MPP	Maximum Power Point
m-CHP	Micro Combined Power and Heat
NG	Nano Grid
PV	Photovoltaic
P_{MPP}	Power Maximum Power Point
RE	Rural Electrification
RES	Renewable Energy resources
RET	Renewable Energy Technology
SHS	Solar Home System
SOC	State of Charge
SOH	State of Health
SRR	Solar Replacement Ratio
T_a	Ambient Temperature
T_c	Cell Temperature
V_{OC}	Open Circuit Voltage
V_{MPP}	Maximum Power Point Voltage
VR	Voltage Regulation
VRR	Voltage Regulation Reconnect
W_P	Watt-Peak

Chapter 1

Introduction

Introduction

Electrical power crisis is one of the major problems in developing countries like Bangladesh, the gap between electric power demand and supply is increasing terrifyingly day by day. Due to high population growth in Bangladesh, the demand for electrical power increases and a number of people are living in energy poverty, despite a continued positive efforts experienced for electrification across all over the Bangladesh [1]. The modern energy system access in the developing countries which are integrating with local renewable energy sources is paramount to resolve the energy shortage. At present, only 62 % of overall people have the access to electricity, whereas urban electrification rate 90 % and only 48 % of rural electrification in Bangladesh [2]. According to the report of Bangladesh Power Development Board (BPDB), the total electricity produced 8,177 MW, while the peak demands 12,000 MW until August 2015. Hence during peak time 32 % of electricity shortage compare to the demand, causes load shedding. Most of the enterprises in Bangladesh along with BPDB limited their electricity supply within the urban areas; while rural access to electricity less than 10 % compares to urban areas. Although 80 % of the population are living in the rural areas, yet about 60 % of the rural population are electrified in Bangladesh. Currently, about 53 % of total electrical power has produced by the public sector and rest 47 % produced by private sector including several independent power producers (IPPs). Most of the power plants in Bangladesh are natural gas based, the future gas reservation cannot meet the demand, and the natural gas based system will be out of phase it is just a matter of time. Now Bangladesh is searching for an alternative solution, as reliable energy sources that can minimize the burden on natural gas and alternative source enhance energy access in Bangladesh. The numerous studies about renewable energy penetration in South Asian country's electricity mix hit up to only 5 %, but next six years the number become double [3] , and the biggest portion will account solar power. In Bangladesh renewable energy contributes 176 MW of electricity including 150 MW has contributed by the Solar Home System (SHS), 16 MW of power from rooftop PV, and 614 kW of solar minigrid, 2 MW from the wind, and 6 MW from Biomass achieved in October 2015.

Yet over 1.3 billion of people not having access to electricity, while 95 % of them without electricity in Sub-Saharan African and South Asian countries, and about 84 % of them are

representing as rural population. Aside from socio-economic context, it has agreed that access to electricity is one of the primary and fundamental conditions to move up from the subsistence economy by rural electrification. Nonexistence of electricity access hampers to progress and development, while limits the opportunities for income, social life standards, education, and health issues. To achieve Millennium Development Goals (MDG), and “vision 2021” a noble vision of GOB; electricity for all, as Bangladesh is suitable geographic location and enormous opportunities from solar, agricultural lands offer the prospect of Biomass immensely. The policies and reformation of the energy sector will restructure opulently endowed renewable energy integrating enormous solar and biomass energy, while modern power system configuration offers dependable and reliable electricity to access.

1.1 Motivation

The whole world is struggling against climate change and global warming terrifyingly, while electricity is producing predominately use of fossil fuel which causes excessive CO₂ emission to the atmosphere, about 8,365 million metric tons of carbon been released which represents all-time high and 1.7 % increases the number from 2006 [4]. In Bangladesh traditionally used fuel including coal and furnace oil is the second and third big shares to contribute electricity which release the higher level of harmful emissions which contains NO_x and SO₂, besides release participle like ash, those does not burn rather pollute the environment frighteningly [5]. Currently, about 99 % of electricity produces from the traditional fossil fuel which contributes the large volume of emission that hazardous for the environment and contributes to global warming, as Bangladesh is the most susceptible climate that contributes about 0.35 % of total global emissions [6].

The global electricity demands been increasing rapidly since last decade, which imposes a great burden on existing electricity producing resources such as coal, oil; thus subsequently in an exponential increases emission and release poisonous substances resulting in environmental pollution, instability, and global warming. In the next 25 years, the global demand for energy is expected to increase by 50 % because of the growth in population and economic development [7] - [8]. It is time to develop sustainable future

with renewable energy, while the large population growth instantaneously increases the demand for electricity and it is commonly agreed that to meet the present demand is the burden for natural gas, for the future alternate source of energy should be cost-effective, environmentally friendly, and enormous capacity. The main goal of rural electrification by renewable sources that complement with socio-economic conditions which eradicate rural poverty, simultaneously transforming away from dependency on fossil fuel [9]. Instead of fossil fuel, Bangladesh has enormous potential on solar PV, and biomass integrated system.

Renewable energy resources in Bangladesh including PV, biomass and hydro has shown significant potential which attracting the attention of future energy system towards sustainability. Renewable energy is also an important alternative for rural electrification deployed by mini-grids or microgrid; because of high oil prices and cost of transmission line expansion, combined with the desire to reduce carbon dioxide (CO₂) emissions. The cost of energy from conventional sources is typically lower than that from renewable energy resources, an energy supply-mix of renewable energy reduce the overall cost of energy in an MG [10], and diesel-based generator provides the reliability in hybrid MG system. Renewable Energy Technologies (RET) has significant potential in Bangladesh, especially biomass and solar integrated power system, the deployment of off-grid PV and biomass hybrid system would be the best option than other conventional power plants those run by sources like gas, coal, and oil. It is contrasted that gas reserve is not sufficient, imported coal and furnace oil expensive and release a huge amount of CO₂, which is threat for climate change. Most of the country have at least one abundant renewable resource and many countries have a portfolio of resources, currently RET plays a crucial part of an assortment of fuel options that are needed for achieving a secure clean fuel and sustainable energy mix, together with energy efficiency and other low-carbon options. A diversified portfolio of renewable energy can provide countries with a number of benefits that are not fully internalized in current energy market prices: (1) Environmental impacts, including greenhouse gas emissions and local pollutants; (2) energy security; (3) strategic economic development, including rural development, the agricultural sector and high-tech manufacturing; (4) energy access through distributed or off-grid solutions[11].

At Present scenario, the power system has dominated by centralized configured power generation system, along with electricity distributed to users through a Macro-grid. Due to increasing the electricity demand while the rise of global emissions of greenhouse gasses, the current centralized energy generation system which is questioned for its future practicability that needs to be restructured to meet the world's growing electricity needs [11]. A Microgrid (MG) is emerging as an integral feature of the future power systems and are considered as a promising alternative to centralized generation. As a localized energy providing system, problems arise along with the processes of design and utilization. The MG have been recently introduced in distribution networks and are defined as small power systems that consist of various distributed micro generators which are capable of supplying a significant portion of the local demand, MG provides multiple benefits to the system including reducing customers' interruption costs, reducing system losses, and accommodating higher penetration levels of renewable resources[12].

According to a report of IEA; Over 1.3 billion people representing 18 % of world population have no access to electricity and 2.6 billion people lack clean cooking facilities. 95 % of them live in sub-Saharan Africa or developing Asia and 84 % of them live in rural areas. Over 1.9 billion people in developing Asia still rely on traditional use of biomass for cooking, and over 100 million in Bangladesh By definition, these people are considered to live in energy poverty as they lack access to modern energy services. Due to population growth, the number of people living in energy poverty is estimated to increase, despite continued efforts for electrification [World Energy Outlook, 2012]. In order to provide affordable energy access to everyone and to combat climate change, sustainable energy solutions are essential [11].

1.2 Aim and scope of thesis

Limited fossil fuels will soon not be enough to meet up the electricity production, imported furnace oil cost increases the price of electricity; electricity-shortage in Bangladesh increases as higher growth in population, and therefore enhanced attention must be given to RES and their utilization to produce electricity. The technological and organizational stability, the electricity sector is undergoing a deep and systemic

transformation that will pose new electricity security challenges and to achieve vision 2021 in Bangladesh. Complement with the geographical location, Bangladesh is predominantly an agrarian country, about 75 % of the population are living in rural and remote areas; agricultural waste has enormous biomass potential. Another strong experienced to use Solar PV powered are important contributors to energy sustainability in Bangladesh and can help economic growth, but integrating these variable renewable energy sources into the power grid successfully. The modern era is looking at the sustainable resources for energy for a permanent solution to the future power demand all over the world whereas the countries of the third world like Bangladesh is still a failure to meet the present basic power demand. Bangladesh which is going to be one of the most prominent and dominating among all developing countries is the failure to its energy demand.

The proposal an optimum decentralized solar-biomass-fossil fuel based MG power system congregate the energy demand. The potential of decentralized MG system in Bangladesh is estimated by the utilization of NASA SSE solar radiation data and Homer Pro Optimization Software, and Graphical representation is very important for research; as MATLAB/SIMULINK would be the best software for analysis data and constraints and present the graphical presentation.

The objectives and aim of this work is to understand the significant meaning of decentralized energy sources especially solar PV and biomass, the potentiality of local available sources and the optimal design of power system that integrated along with renewable energy sources. The distribution network proposition with distributed generating sources and distributed load shares the generated electricity, and system should be reliable and efficient. The outcomes of the thesis will be provided a better understanding of denaturalized microgrid, the generation and consumption followed by multi agent system but decentralized control in each participants (SHS) enhance flexibility and performance. Microgrid equipped with intelligent elements from smart grids has been adopted and active control of small scale energy resources is included in such smart Micro grid. The issues enclosed in this work and contributions of this thesis; efficient and reliable energy management system design within decentralized microgrid, where the consumers reduce the peak demand and share those among other participants in the system. The configuration of the system integrate with local renewable sources and

enable to connect with the existing grid, fair settlement price for participants in the proposed micro-grid. Secondly, problem for sufficient energy and fair cost distribution

The objectives and aim of this work are to understand the significant meaning of decentralized energy sources especially solar PV and biomass, the potentiality of locally available sources and the optimal design of power system that integrated along with renewable energy sources. The distribution network proposition with distributed generating sources and distributed load shares the generated electricity and the system should be reliable and efficient. The outcomes of the thesis will be provided a better understanding of denaturalized MG, the generation, and consumption followed by the multi-agent system but decentralized control in each participant (SHS) enhance flexibility and performance. A MG equipped with intelligent elements from smart grids has been adopted and active control of small-scale energy resources is included in such smart MG. The issues enclosed in this work and contributions of this thesis; efficient and reliable energy management system design within decentralized MG, where the consumers reduce the peak demand and share those among other participants in the system. The configuration of the system integrates with local renewable sources and enable to connect with the existing grid, fair settlement price for participants in the proposed MG. Secondly, the problem for sufficient energy and fair cost distribution among consumers; including SHS sharing common micro-grid is considered. As each consumer competes with others neighbours to obtain lowest energy bill by sharing electricity. An innovative approach of rural electrification by sharing electricity among all contributors including centralized Biomass Generator and decentralized SHSs. The development of the system would be designed, modeling, and planning based approach which will enable to integrate local renewable energy generation and storage (such as Solar Home System). By connecting all SHS, BHS (battery home system), centralized storage and generation into DC-MG. The objectives of the thesis consisting of;

- 60-80 % of renewable energy utilization for an optimum decentralized solar-biomass-fossil fuel based MG system congregate the energy-demand
- The Control and Energy Management Strategy for SHS and MG
- Study the concept of optimal configuration of MG
- The Optimization and Sensitivity analysis would be done by Homer Pro Software
- Mathematical based Modelling and Simulation done by MATLAB/SIMULINK

- Planning, sizing, and optimization of MG; the optimal design feasibility analysis and feasibility analysis and investigate the various configuration of the optimum system by HOMER Pro microgrid software for design and optimization.

1.3 Outline of thesis

The Thesis work will be including about this chapter, the motivation and aim and scope of outcomes. Rest of the chapter is divided into 5 chapters.

Chapter **2**: Energy Access in Bangladesh

A short description of overall Electricity profile and Power sector in Bangladesh, the infrastructure of Power sector. Short description and concept of rural electrification and an innovative approach of rural electrification to access electricity. Also, portray background information on Bangladesh; electricity of market, Renewable potential and sustainable development. The projects partners and organization are presented and previously worked described in Bangladesh.

Chapter **3**: Stand-alone PV System and MG Configuration

Concept of MG, and along its different components such as PV and biomass sources and potential in proposed location in Bangladesh, brief description of each individual element used in proposed MG system. Concept of Solar Home System (SHS) and its individual components including households loads different mode of micro grid, integration of renewable resources within the proposed micro grid.

Chapter **4**: Modelling and Simulation result and Discussion

System Design, modelling, and simulation of DC-MG in MATLAB SILULINK based environment, Decentralized Energy Resource in the system like PV module design, modelling and simulation. The PV module design considered to temperature dependent and PV array modelling follow up and simulation will be done on specific whole day respect to different solar insolation in every minutes. The solar home system (SHS) design, and modelling and simulation also in SIMULINK. In the MG, there will be 2 different types of SHS; named as large size SHS and regular size SHS, while the typical lead acid battery also simulates along with PV modules. The MG operation and electricity-consumption, forecasted renewable energy output in proposed rural location in Bangladesh. Analyse and characterize the system components as steady state and the simulation cases that are evaluated. Present an introductory concept of the simulation tool HOMER that is used to evaluate different cases for the production system configuration.

Chapter 5: Planning, Sizing, and Optimization of MG

Discussion and analysis of simulation system that evaluated. Technical comparison to previous work also included. Proposition of distribution system and distribution loss is calculated based on chosen conductors and Inverter losses.

Chapter 6: Conclusion and future work

Discussion and ending up with recommendation of proposed MG operation and design. The limitation of the thesis will be further considered for future study and research.

Chapter 2

Electric Energy Access in Bangladesh

Introduction

The IEA estimates approximately 1.5 billion people have no access to electricity in 2008 [13], which estimates more than 20 % of the total population in the world. According to UNDP report, more than 96.2 million of people which is more than half the total population in Bangladesh still remains without access to electricity [14], furthermore irregular power supply causes load shedding. Electric energy access is a far away dream for many families in the rural areas in developing countries, about 80 % of the population are living in the rural and remote areas in Bangladesh where only 25 % of the population have access to electricity. To overcoming the curse of poverty, a sustainable economic growth developed by energy access, and electricity is an essential prerequisite and major criterion for success. Electricity access with the modern form of energy resources is promoting social and economic growth. It is also an indispensable contribution to achieving Millennium Development Goal (MDG) and vision 2021. In the modern era, there is no country attained sustained economic growth without improving access to clean and modern energy; the modern form of energy delineates with the integration of locally available renewable energy sources. Rural electrification ensuring with improved electricity is fundamental for socio-economic development. Electrical energy access influences to the life standards, which affecting agricultural productivity, education, health. The government of Bangladesh has set a noble vision to access electricity for all inhabitants by 2021, to comply the vision integrating solar PV and biomass sources which are richly endowed in Bangladesh.

In Bangladesh, it is commonly agreed that about 4-6 h of power outage per day in rural areas, but summer season the number of hours rises to 6-8 h, the circumstances mostly during 18:00 h to 22:00 h irregular power outage causes load shedding. The demand for electricity increases with increasing with Population but the generation of electricity is not increasing to meet the demand. At present, almost 52 % of total people in Bangladesh are connected to the grid [15], the power supply from the grid is inadequate to meet both peak and basic demand in Bangladesh. Almost 75 % of people in rural areas are not connected to the main grid, and only 15-20 % of electric demand comply by the BREB (Bangladesh rural electrification board) supplied electricity [16]. Due to change of life standards and social impact which enhance the electricity consumption rate and the rate

increased by 5.43 %, but the generation of electricity increased only at the rate of 5.37 % that increased the rate of 6.72 % load shedding per year [17], graphically present in figure 2-3. According to LEAP (long range energy alternative planning) project [18], rural households loads comprises with lighting, mobile charger, ceiling fan, TV, and refrigerators. In rural areas lighting is the main loads in the rural households. In 2010 rural households, consumes 300 kWh per year for lighting solely satisfied by electricity supplies. The demand for evening lighting growing at constant 1.67 % per year energy consumption for lighting purpose up to 350 kWh by 2020 [19]. A tropical country like Bangladesh, where summer seasons comprises almost 9 months requires cooling by a ceiling fan, consumes 250 kWh per year and assume the consumption rate increase up to 1.9 % and per capita consumption will be 345 kWh in 2030. Likewise, refrigeration consumption demand rate increases 0.93 %, the energy consumption increase from 476 kWh to 565 kWh by 2030.

According to EIA (Energy Information Administration), Energy access for rural electrification; “a household’s entails reliable and affordable clean energy for cooking, electricity requires to meets the minimum level of consumption loads over time”. The percentage of energy consumption has experienced promptly increasing about 2.69 % from 2012 to 2013, but still remains lowest per capita consumption. The studies form EIA, the consumption has increased dramatically over 52 % within the past decade. [20].

2. 1 General Country Profile

Bangladesh is moving towards achieving the tag of Developing country with an annual GDP almost 6 % over the last past decade [21]. Recently population thriving dramatically nearly 158 million and annual growth rate of 1.39 % over the past decade [22]. The majority of them are living in the rural areas, and only 32 % of households have access to electricity, but the availability of electricity about 22 % [23]. Bangladesh is one of the largest in population at 9th position in the world with 158 million people at the end of 2014, where total 52 % people have partially electricity access, while only 10 to 15 % of rural have the access to electricity demand mainly meets the light, ceiling fan, refrigeration, irrigation, productive uses loads. In Bangladesh, the electricity demand of

all sectors including agriculture, commercial service, industry, and domestic services. The domestic households and industry sectors are consuming of electrical power about 43 % and 44 % respectively in the total of about 87 % [24]. The GDP growth rates is significantly depend on the production of a country, as Bangladesh is an agricultural and small size industrial production based country, and production always depends on electricity, the GDP growth and electricity generation growth present in figure (2-1). It is estimated that, increase in 1 % of per capita energy consumption causes an increase in per capita GDP by 0.23 %.

2.1.1 Climate and Geography of Bangladesh

Bangladesh is located between 20° to 26° North and 88° to 92° east. It is bordered on the west, north, and east by India, on the southeast by Myanmar, and on the south by the Bay of Bengal. Most of the country is low-lying land comprising mainly the delta of the Ganges and Brahmaputra rivers. Floodplains occupy about 80 % of the land in Bangladesh. Mean elevations range from less than 1 meter on tidal floodplains, 1 to 3 meters on the main river and estuarine floodplains, and up to 6 meters in the Sylhet basin in the north-east [Rashid, 1991]. The land is a deltaic plain with a network of numerous rivers and canals. The total area of the country is 147,570 km², in which about 17 % is forested. There are a few hilly areas in the southeast and the northeast of the country [25]. Bangladesh enjoys generally a sub-tropical monsoon climate while there are six seasons in a year, with three being more prominent, namely winter, summer, and monsoon season. Winter begins in November and ends in February. In winter, there is not much fluctuation in temperature, which ranges from a minimum of 7 to 13°C to a maximum of 24 to 31°C. The maximum temperature recorded in the summer months is 37°C although in some places this occasionally rises up to 41°C (105°F or more). Monsoon season starts in July and lasts up to October. This period accounts for 80 % of the total rainfall. The average annual rainfall varies from 1,429 to 4,338 mm [25]. Bangladesh is called (in Bangle Vadir desh) or ebb-tide country. Day by day its sea level has been increasing. If world's carbon dioxide giving out is not controlled, then melting down of the pole also continues. For which our coastal area may go under water. This threat is the upcoming risk for Bangladesh [26].

The climate of Bangladesh is subtropical and tropical with temperature ranging from an average daytime low of 21 °C in the cold season to top of 35 °C in the hot season. Annual rainfall varies from 1000mm in the west to 2500 mm in the southeast and up to 5,000 mm in the north near the hills of Assam. Three-quarters of the annual rainfall occurs between June and September. The humidity from 90 % to.95 % observed in the season is almost unbearable. The humidity remains high all year round, producing thick fog in winter, and making a chilly night in the north feel much colder than they are. Bangladesh has three main seasons: the monsoon or wet season from late May to early October; the cold season from mid-October to the end of February; and the hot season from mid-March to mid-May. Three or two cyclone seasons-May to June and October to November [27]. The annual rainfall and average temperature represents in Appendix-3 and Appendix-4 simultaneously.

2.1.2 Energy Sector in Bangladesh

Electric energy is one of the affable terms of energy which is the fundamental contingent for socio-economic development, which alleviate poverty. But, Bangladesh has the major problem of the energy crisis that persisting poverty, conventional fossil fuel causes environmental degradation. Merely, 49 % of the population have the access electricity that met by 4,500 MW while peak demand 6,000 MW causes a power outage. Currently, 53 % electricity produced by public sectors and rest produced by several private sectors with various form of generation[28]. The existing available power generation 10,500 MW by October, 2014 and vision set to 39,000 MW by 2030 [29]. The table (2-1), represents power generation from different organization and Bangladesh Power Development Board (BPDB) transmits and distributes across the country. Natural gas and coal expected the main source of power generation in Bangladesh, GOB also attentive on liquid fuel based power generation. The conventional fuel consumption to generate electrical power and traditional power plant influenced to increase CO₂ emission, power generation sector alone contributes 40 % CO₂ emission [30]. The primary energy considered to consumption estimated 62% of biomass, 25 % of natural gas, 12 % imported oil, and coal and hydropower contribute 1 %.

In Bangladesh, power sectors that highly dependent on conventional fossil fuel including natural gas and coal. The total capacity of electricity generation about 10,709 MW, and 70.39 % of electricity generation by natural gas present in figure (2-1). Besides natural gas, 10 % high-speed diesel, 5 % of coal, and 3 % of heavy fuel oil used to produces electricity [31]. Only one hydropower PV and biomass contribute to total demand. Total power generation concerning fuel; 5,730 MW by natural gas available in the local region, 1,876 MW by imported furnace oil, 511 MW by imported Diesel, 220 MW from hydro, and 200 MW by coal [32].

Table 2-1: Daily Power Generation

Company	Demand (MW)	Day peak (MW)	Evening peak (MW)
Power Development Board	4332.00	1767.00	2702.00
Electricity generation company Bangladesh Ltd	622.00	0.00	0.00
Ashuganj Power Station Co. Ltd	1617.00	723.00	896.00
Independent Power Producer (private)	325.00	248.00	283.00
Small size producers	1987.00	1269.00	1440.00
Rental Power Producers	825.00	1101.00	1189.00
Total generation	10390.0	5515.0	6987

According to (BPDB) report expresses, 55 % of people have access electricity, and per capita 321 kWh electricity generation [33], which comparatively lower than other developing countries. Access to power in Bangladesh is limited to about 45 % to 50 % of the population and those who have access faces severe power shortages. Load shedding in Dhaka in 2011 and during the summer of 2012 was about 5 hours per day. Power shortages have constrained the potential economic growth in Bangladesh and cost of which have been estimated to be about 0.5 % of GDP. According to “Vision 2021”; the government’s vision for the power sector is to ensure universal access to grid electricity by the year 2020, with an interim target to reach an access level of 68 % by the year 2015. According to government estimates, about 20,000 megawatts (MW) of new generation

capacity need to be added to the system by 2020, together with matching transmission and distribution improvements to reach the universal access [34].

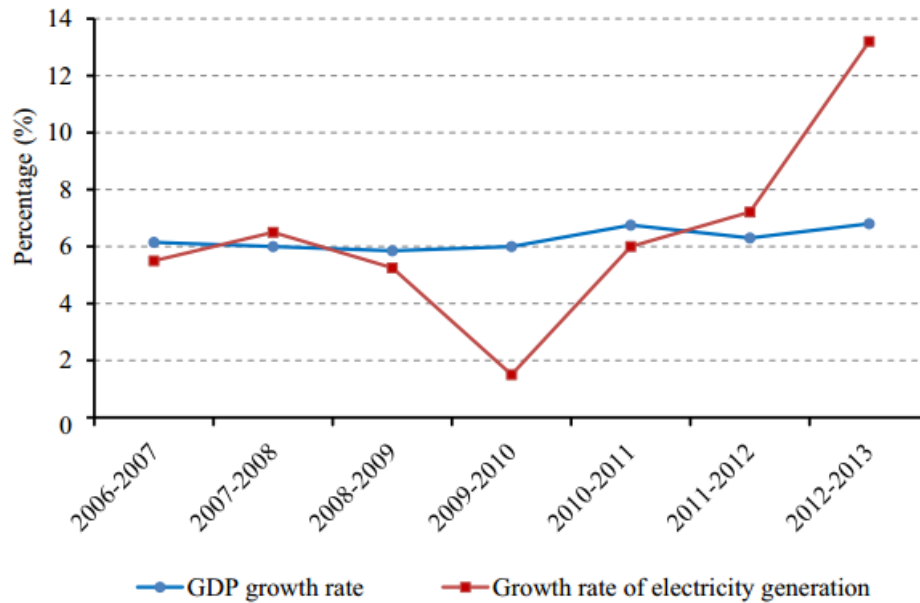


Figure 2-1: Relationship between electricity generation and GDP growth rate [35]

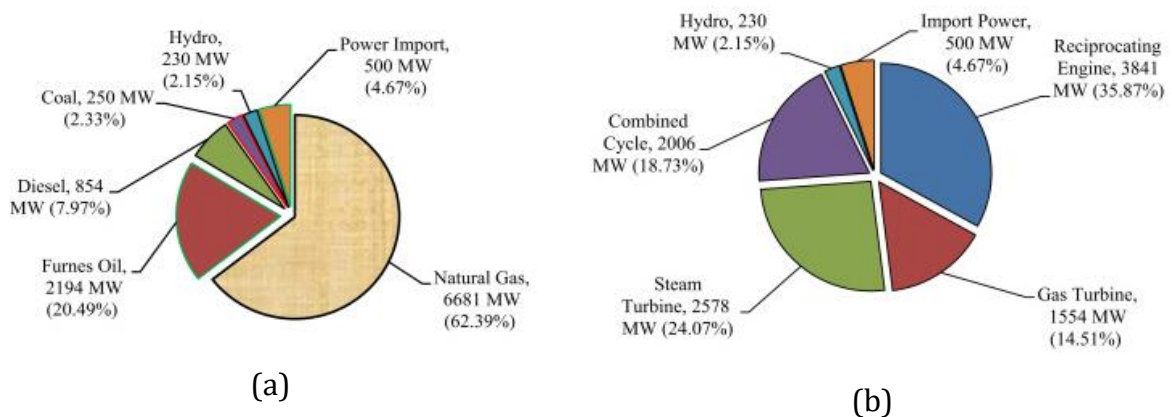


Figure 2-2: Installed electricity capacity (A) fuel type and (B) plant type [36]

The total installed capacity was 5,262 MW in FY 2007 to 08, which has increased to 8525 MW in FY 2012 to 13 with an annual increase of 10.34 %. However, the maximum generation was 4,130 MW in FY 2007 to 08, which has increased to 6,350 MW in FY 2012 – 2013 with an annual increase of 8.96 %. The annual rise in the maximum generation (8.96 %) is lower than that of the installed capacity (about 10.34 %) between the FY 2007 – 08 and 2012 to 13. This is mainly due to the less generation capacity of older power

plants and shortage of natural gas supply. The power generation capacity has increased more than 8,000 MW in FY 2012 to 13, whereas the capacity was over 5,000 MW in FY 2005 to 2006, while the demand of electricity increases from lower than 5,000 MW to over 8,000 MW in FY shown in figure (2-5).

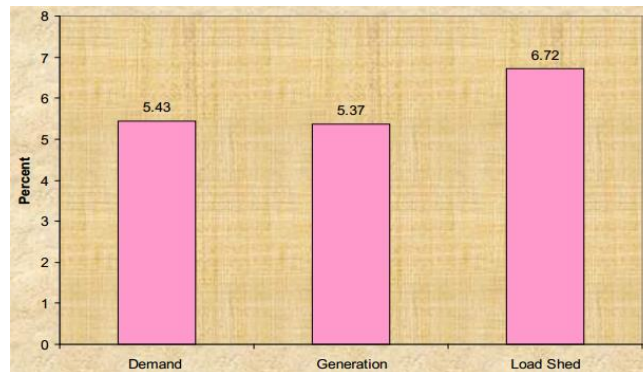


Figure 2-3: Growth rate of Demand, Generation and Load Shedding [37]

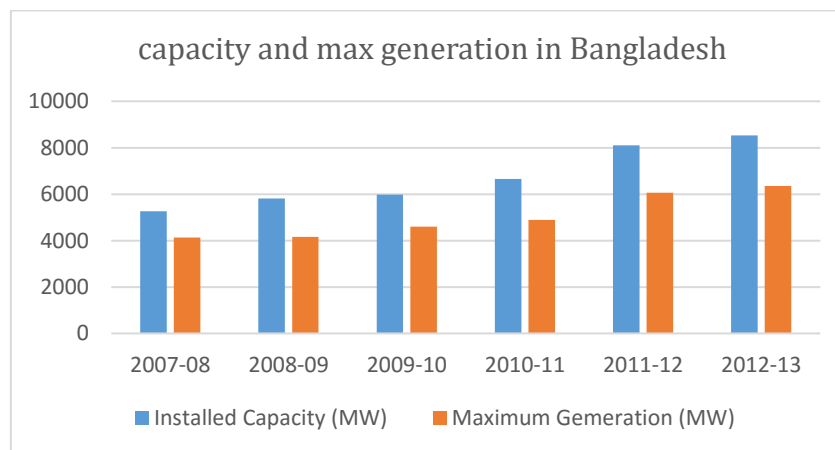


Figure 2-4: Installed Capacity and Highest Generation of Power in Bangladesh [24]

Table 2-2: Different Fuel Consumption

Gas	Diesel	Hydro	Coal	Furnace
4,822 MW	186 MW	230 MW	250 MW	335 MW
82.81%	3.19%	3.95%	4.29%	5.75%

Though attribution is difficult, this technical assistance may have played a role in supporting a 'balanced development' of the power sector, which during the project period (2004-2013) saw an increase in electricity access from 35 percent to about 62 %; an increase in generation capacity from 3,622 MW in 2004 to 9,500 MW; a reduction of systems losses from about 20.0 percent to 1.3 percent; and a drop in accounts receivable from 6.45 months to 2.21 months. About 40 % of electricity generated by private enterprises by April 2010 while the number has been increased to 44 % by April 2011. Currently, rental, quick rental, and some others peaking plants were undertaken on a first track based power generation to manage present power crisis. According to the Power System Master Plan (PSMP, the peak demand anticipated 10,283 MW in 2015, whereas total power generated about 12071 MW. The peak demand will be 25,199 MW anticipated in 2020 and 33,708 MW in 2030 show in figure (2-6). Electricity distribution through authority shown in the table (2-3).

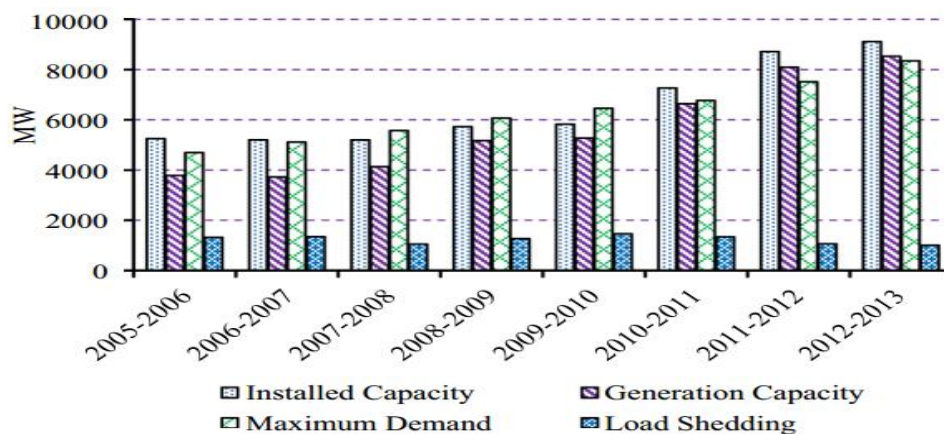


Figure 2-5: Electricity generation vs Crisis from 2005-2013 [36] [38]

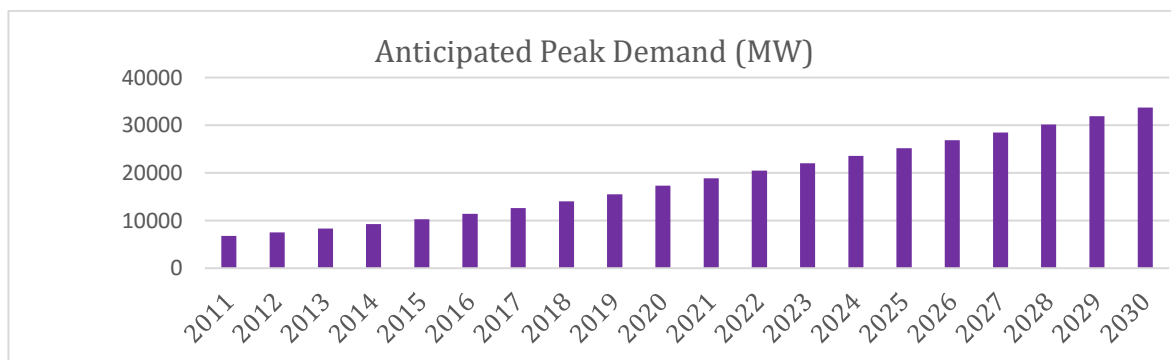


Figure 2-6: Yearly Anticipated Peak Demand

2.1.3 Infrastructure of Bangladesh Power development

Bangladesh Power Development Board (BPDB), is the sole authority to delivered electricity to the national grid through a common transmission line, to meet the national demand BPDB produces and purchases electricity from independent power producers (IPPs). The five authorities contribute together to produces electricity in Bangladesh:

1. Bangladesh Power Development Board (BPDB)
2. Ashuganj Power Station Company Ltd. (APSCL)
3. Electricity Generation Company of Bangladesh (EGCB)
4. North West Power Generation Company
5. Independent Power Producers

Table 2-3: Share of electricity distribution by Authorities in Bangladesh

Authority	BPDB	DPDC	DESCO	WZPDC	REB
Share (%)	24.64	18.59	10.51	6.17	40.10

Bangladesh power system including transmission system comprises along with 16 substations capacity of 230/132 kV besides that 103 substations dimensions of 132/33 kV substations, which total capacity of power contains 7,525 MVA and 11,892 MVA respectively. The distribution network comprises 33 kV, 11 kV, and 400 V [39].

Table 2-4: Authorities Involved Power Generation and Capacities and Market Share

Name of Authorities	Capacity (MW)	Market Share (%)
Bangladesh Power Development Board (BPDB)	4442	42.75
Ashuganj Power Station Company Ltd (APSCL)	682	6.56
Electricity Generation Company of Bangladesh	622	5.98
North West Power Generation Company Ltd	375	3.06
Independent Power Producers (IPPs)	4269	41.08
Total	10,390	100

Considering country size and population, Bangladesh electricity infrastructure is quite smaller than other countries which is insufficient and poorly managed by several authorities including BPDB, BPDC, DESCO and REB. Amongst all these authorities, REB is one of the most success government company since 1977 in Bangladesh, and 40.10 % of the total electricity generation used to electrifying the rural areas.

2.2 Rural Electrification

South Asia accounts for 37 % of the world's population without access to electricity [40]. Such a situation continues to exist despite several initiatives and policies to support rural electrification efforts by the respective country governments including the use of renewable energy technologies including PV, wind, and biomass. The pace of rural electrification over much of the developing world is excruciatingly slow. In many countries in South Asian and Sub-Saharan African, it is even lower than rural electrification growth in Bangladesh. Bringing the socio-economic development into the development countries like Bangladesh, the essential elements considers rural electrification [41], development of underprivileged rural people [42] [43]. The present demand of electricity for improvement of living standard, agricultural production, and community development in Bangladesh, the access to electricity through rural electrification still not sufficient enough, but the impressive growth of SHS and off-grid PV system in Bangladesh. Development and implemented by IDCOL (Infrastructure Development Company Limited). In figure (2-7) presents the electrification access in both urban and rural areas of deferent districts in Bangladesh.

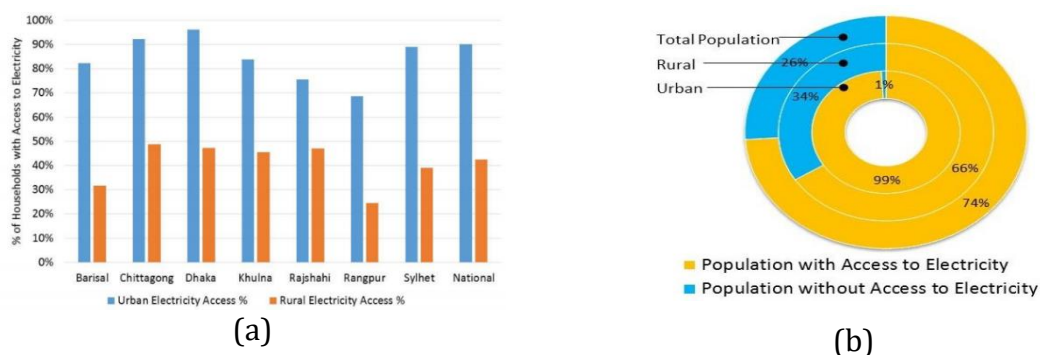


Figure 2-7: (a) Urban and rural electrification; (b) Energy Access [44] [45]

Electrification rate in rural areas still poor as only 38 % of households are electrified [23], IDCOL (Bangladesh Government owned agency) with other 30 partners Organization (POs) working together for improving the access of electricity around rural areas. Despite continuous efforts from the international community and governments, the pace of rural electrification still very slow [46]. The Bangladesh Rural Electrification Program (BREP) clearly expresses which benefit greatly from the involvement of local communities improve electricity access in rural areas. According to the vision 2021; GOB aims at 100 % access to electricity to entire rural areas by 2020, Connecting over 0.7 million consumers and only 3 % of electricity supplied by the REB, the dedicated government organization, rest of can be supplied by the including private company and partner organization (POs). The process of rural electrification in developing countries, which depends on various factors;

- i. The result of pre-phase economic and social impact
- ii. Development of PBS
- iii. Technically and financially power system
- iv. Available funding from international community

There is main process of electrical access in rural areas centralized approach and decentralized approach; centralized approached constituted by government and partner stakeholders. In Bangladesh REB and BPS are the main organization for rural electrification. The decentralized approach formulated by both top-down and bottom-up concept, standalone PV system, SHS, and renewable integrated hybrid mini-grid the best example in Bangladesh. The approach follows up and development of rural electrification in Bangladesh considered;

- i. Extending and intensifying the central grid
- ii. Deploying off-grid technologies (off grid mini-grid, standalone MG, bottom up swarm electrification)

2.3 Renewable Energy penetration in Bangladesh

According to IEA Energy Access to comply the rural electrification, household having reliable and affordable electricity to clean cooking facilities, first electricity connection,

and increasing the level of electricity consumption over time as regional average. Bangladesh is the most potential country for renewable energy, significantly increases the number projects to meet the electrical energy throughout the country. The most existing form of renewable energy experienced in Bangladesh considering PV based off grid system including SHS, nano-grid, MG and mini-grid, where biomass also has high portentous to integrate significantly in the power system. With increasing both life standard, socioeconomic through urbanization is growing in developing countries rapidly, to meet the urbanization growth electricity demand also increases promptly in Bangladesh. The GOB has set a target about 90 % electricity access across the country by 2018 [47], to meet this vision innovative rural electrification integrated renewable energy is the best solution followed by the recent experiences, and achieving the target 2018 by connecting 450,000 households per months by 66 % of SHS, and hybrid power system with renewable sources.

Although Bangladesh is the seven largest natural gas producer country among Asia, about 56% of gas consumption as the primary source of energy. As high dependency on natural gas, and experiences shortage of gas supply. The regular peak demands 5,500 MW, but only 4,000 MW of electricity produced by the conventional power generation system that causes rolling electricity blackout. Remote areas and rural villages are the major mechanisms of holistic society; the development of socio-economy and environmental prominence in Bangladesh depends on productivity, and productivity depends on access to energy. But the true reality is a government of Bangladesh not frequently involves for rural development including rural electrification due to some geographical constraints. In figure (2-8) represents, the electricity access increasing rapidly from 2000 to 2015.

Electrifying in rural areas by conventional electrification system is expensive due to households are situated scattered and remote, and consumption rate low compare to urban electrification. Hence, no- electrified remote areas and poor villages electrifying by the conventional basis not promoted and focused. Consequently, it is urgent for the development of social life in Bangladesh by the availability of the reliable, adequate, and reasonably priced source of energy that uninterrupted balance of electricity supply.

Many countries and cities have already moved towards the low carbon and clean energy transformations. Germany, for instance, is undertaking the 'Energiewende', an economic turning point that aims to produce 80 % of its electricity from renewable by 2050 [48].

Harnessing clean, renewable, and more efficient energy solutions will contribute not only to tackling a country's or community's energy challenges but also to the target of limiting global temperature rises to 2°C. As it is, a significant amount of GHG emissions are generated from energy production, thus tying sustainable energy directly to the climate change negotiations.

Bangladesh today faces a different future than it did decades ago when abundant natural gas seemed to be the key to prosperity. At the same time as the centralized grid-based electrification has been the most common approach, decentralized renewable energy options especially, PV(photovoltaic) systems has also been adopted, especially for areas where it is techno-economically not feasible to extend the electricity grid. These off-grid communities are generally small, consisting of low-income households with characteristics that may have been economically unattractive to electricity distribution companies to extend the grid. Small-scale renewable energy options, such as a solar home system (SHS) and biogas plants, have evolved as a promising alternative for providing electricity to these disperse areas [49]. Other renewable energy options, such as wind energy and hydropower, have little potential to contribute to rural electrification in Bangladesh. Among the renewable technologies, the SHS option has accounted for the major share (80 %) of off-grid technologies in Bangladesh [50] [51] [52]. Bangladesh started its intensive rural electrification program in 1977 when only 10 % of its total population was connected to a grid. The country adopted a rural electric cooperative (REC) concept from the National Rural Electric Cooperative Association (NRECA), which had successfully electrified rural America in the 1930 [53]. To implement the rural electric cooperative concept in Bangladesh, a central statutory agency called the Rural Electrification Board (REB) was formed by the government. The REB was given the responsibility of organizing the rural electric cooperatives (Palli Bidyut Samity, PBS); it employed managers to oversee the financial and administrative activities of the cooperatives. According to the World Bank manifesto, to bring most of the people electrifying under project "Rural Electrification and Renewable Energy Development" which mainly deployed by PV system [54].

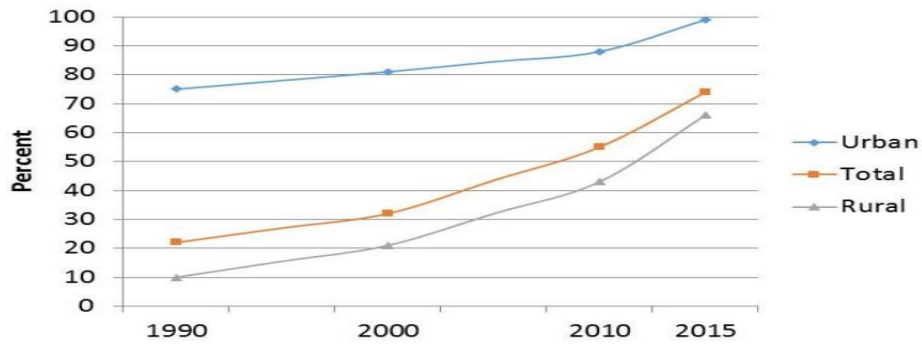


Figure 2-8: Change in Access to Electricity, 1990-2015 [44]

Amongst all 49 partners' organization, and IDCOL has developed a competitive market for Solar PV system without any geographic constraints by offering solar incentives; SHS installation, PV system with battery and charge controller supplies across the country [55].

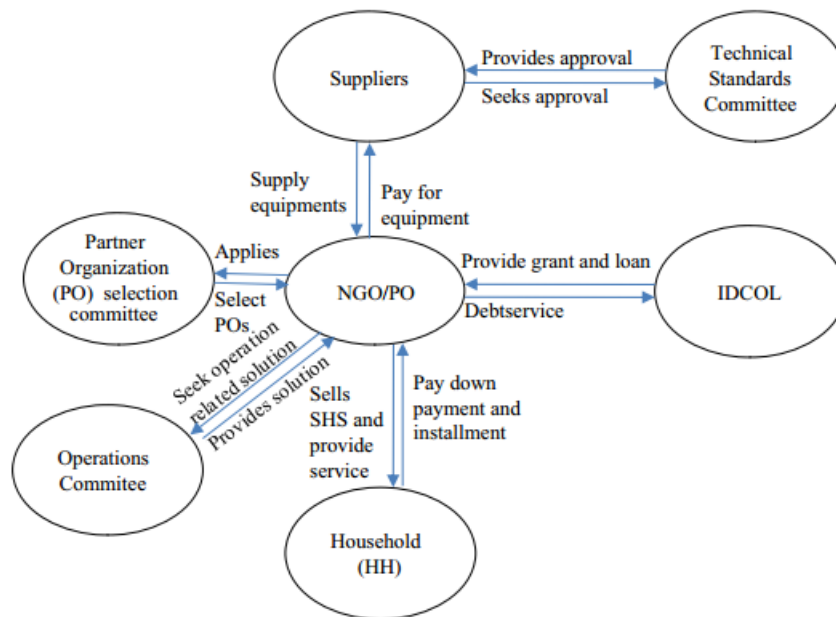


Figure 2-9: Institutional development for off-grid program [56]

Achieving quality and reliability of electricity supply is an important factor for each region, enhancement of reliability factor in integrating intermittent renewable energy like solar and the wind no choice except diesel generators, issues highlighted by (Foster and Steinbuks, 2009), estimates power system that generators owned compensated by 6

% of total capacity in sub-Saharan Africa and other low-income countries up to 20 % [57]. Renewable electrification inspiring by the institutional framework in Bangladesh present in figure (2-9). Since renewable energy emerging in the power system of Bangladesh, the capacity gained 78 MW until 2012 which about 95 % of solar energy [56]. To comply the master plan, targeting 30 million of population electrified by the off-grid system by 2016 which is about 18 % of total rural population, whereas the number was about 15 million in 2013.

2.3.1 Biomass Potential

It is proved that Bangladesh has significant potential in biomass and biogas. Bangladesh is a tropical monsoon region, and agricultural is the main income for people who are living in the rural areas. Agricultural waste provides an enormous amount of biomass resources assimilate with animal waste, household waste and MSW (Municipal Solid Waste) which utilized to produce the large scale of electricity. Biomass generation system offers a number of advantages, mainly sources in low cost but high in energy efficiency compare to other fossil fuel, which reduces fuel costs. Besides electricity generation, biomass waste also affords fertilizer simultaneously. In Bangladesh gas is the main source of electricity production, according to [58], about 88.8 % of electricity have generated by domestic gas and a big part of electricity generation from imported furnace oil. In Bangladesh, from agriculture produces rice, wheat, maize, coconut, vegetables, jute, sugarcane, etc. About 46 % of biomass energy sources from rice, straw, rice, husk, jute stick, sugarcane [59]. Most of the households in Bangladesh produces their vegetables and summer and winter accounted 48.16 % and 51.84 % respectively in the year 2011 [60].

Power generation from biomass gasification is reasonably novel in Bangladesh and favorable technology. Electricity generation by biomass gasification can be solved our day to day problem at the immense scope. Eventually, the purpose of rural electrification which is the expression of grief need of Bangladesh. In addition to producing electricity, it is advantageous to the agricultural and industrial expansion and production. It is almost impossible without rural electrification to fulfill Bangladesh Government vision of ensuring access to reliable and affordable electricity for energy security-2020. The

traditional biomass and natural gas are the major sources of energy in Bangladesh, whereas 70 % of biomass energy consumption of total energy consumption [50]. Biomass is promising technology convert energy from all-purpose living materials including plants, animal, fungi, and bacteria. As Bangladesh is densely populated country, the opportunity of reuse for productivity would be the best usage of efficiency. Biomass encompasses of agricultural residues in Bangladesh mainly rice, maize, wheat, coconut, groundnut, bean, vegetables, jute, and sugarcane etc. About 46 % of total Biomass energy has produced from agricultural crop residues. Rice is the main agricultural crop, and 70 % of rice husk energy is consumed. At present NGOs are promoting small scale biomass system for clean cooking and electricity generation. There are two minor projects which supported by IDCOL those generating 200 to 300 kW by using poultry litter, moreover, the studies also suggested that up to 800 MW of electricity by poultry waste litter. At present 15.00 tons of poultry litter produced each day, and a small fraction being used recycle. About 47 tons of waste expected, will be produced in 2025. In Bangladesh another available but significant raw material for biomass production rice husk, several searches showed that up to 400 MW of electricity can be generated single-handedly by rice husk.

2.3.2 PV potential

Bangladesh is blessed with enormous solar potential, as solar insolation. The average solar energy incident from 4 kWh/m²/day to 6.5 kWh/m²/day, with average 10.5 solar hours and about 300 clear sunny days. By combination of solar cell in PV module, under standard test condition (STC) module produces DC electricity at range 100 to 400 W. In figure (2-9) shown, clear bright sun light, except June and July average 7 to 9 h operates rest 10 months to produces solar energy. In the figure 2-10, represents monthly average solar irradiation in different regions in Bangladesh. The different solar insolation for different district in Bangladesh have shown in figure (2-11).

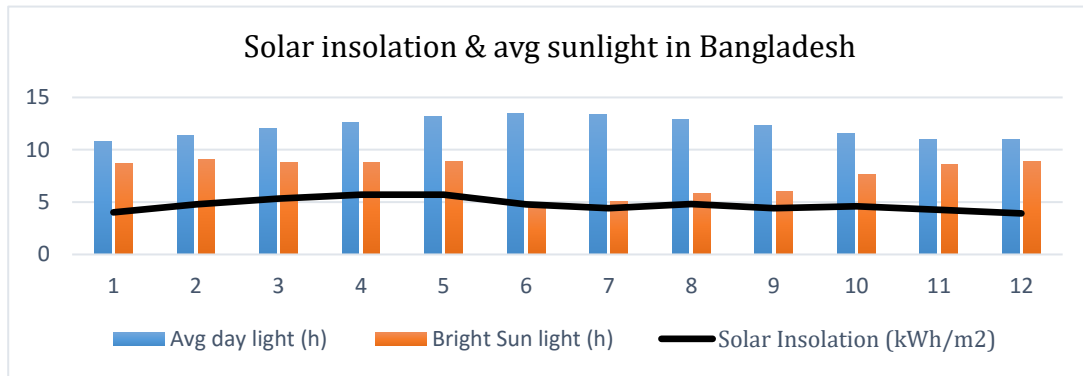


Figure 2-10: monthly solar average irradiation, average Sunday light

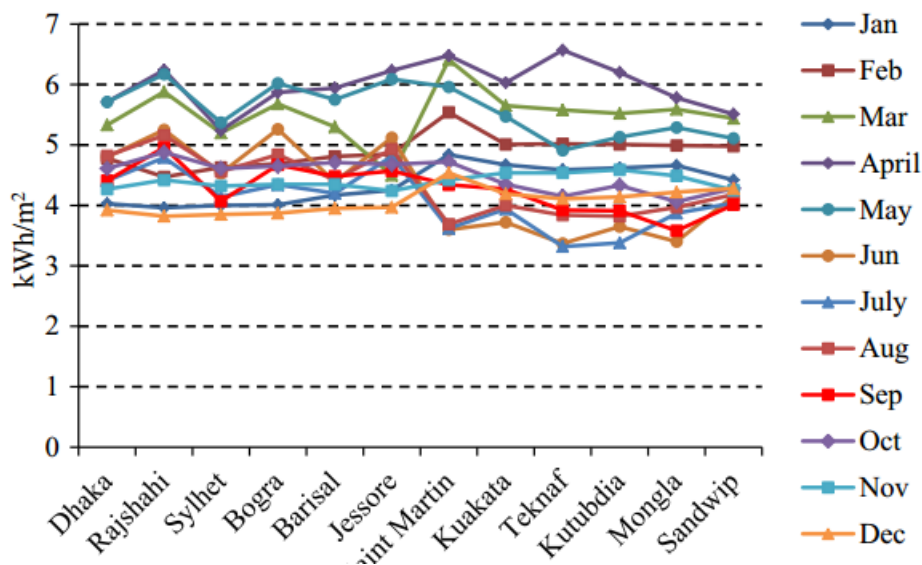


Figure 2-11: Solar radiation of some selected area in Bangladesh [61] [62]

2.3.3 Solar Home System in Bangladesh

Solar sources and SHS has experienced a great success in Bangladesh, particularly the improvement of rural electrification. Currently, about 42 % of people have access electricity and per capita consumption of electricity is about 133 kWh in 2005 [63], which is the lower comparatively other developing countries. Nevertheless, the imbalance power supply makes the big difference between demand and supply, which makes load shedding. Started early in 1980, PV flourished across the country and the success factors focus on;

- i. Rural areas electrified which is not yet accessible into the grid
- ii. Remote areas where electricity access is almost impossible
- iii. Insufficient power supply

SHS generated electricity mainly used in rural households' loads including low power devices, CFL or LED lights, TV, mobile charger [64]. Bangladesh annual variation of inclination of the sun, measured from the vertical varies from 0 degree to 46 degrees between the summer and the winter. Summer days are longer, around 14 hours, with average sunshine more than 6 kWh/m²/day on the clear sunny day. Although winter days are shorter around 10 h, still there is more than 4.5 kWh/m² per day of insolation on a clear sunny day. Solar Home System (SHS) are stand-alone photovoltaic systems that offer a cost effective mode of supplying power for lighting and appliances to remote off-grid households. In remote areas, which are not connected to the grid; SHS can be used to meet remote household's energy demand. In Bangladesh, SHS usually at a rate of 12 V DC and provide power for low power DC appliances including lights, TV, mobile charger, for about four to five hours.

In developing countries like Bangladesh, where the national grid extension is not economically and technically feasible, an array of PV cells is used to build solar home systems (SHS). The main components of SHS include a solar panel, battery and a charge controller which can be operated with minimum training [65]. Over the past decade, since the Bangladesh government launched a rural electrification program supported by World Bank and other international aid bodies, the number of off-grid installations in the country has rocketed. In 2002, installations rates stood at 7,000; today the figure has exploded to nearly 2 million and continues to counting, with average installation rates now topping 80,000 months [66].

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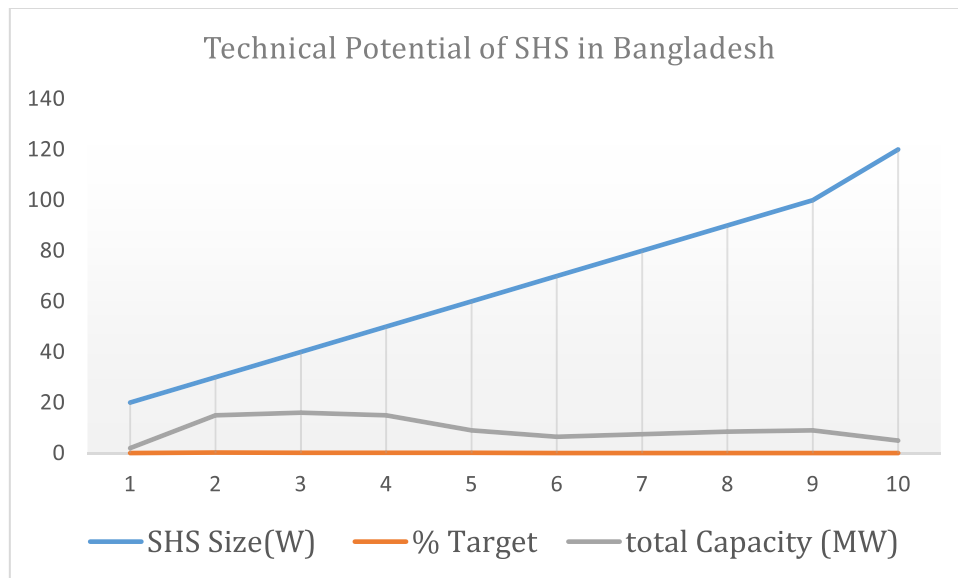


Figure 2-12: SHS potential and installed capacity in Bangladesh

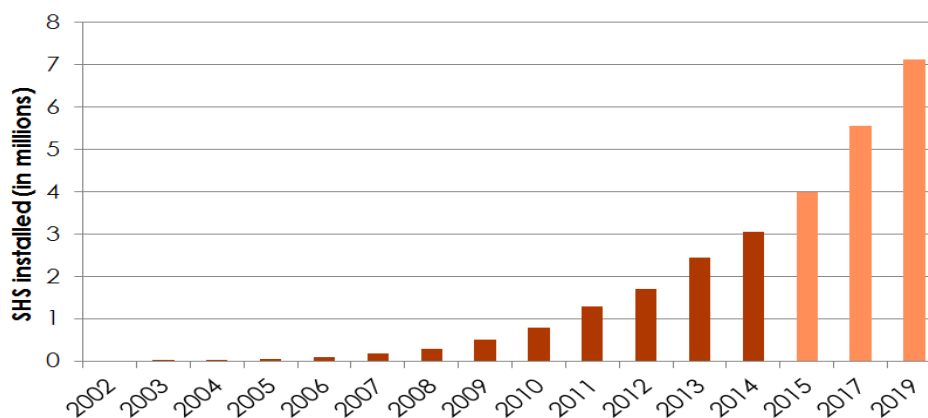


Figure 2-13: IDCOL SHS Program and Growth rate [67]

IDCOL with other partner organization financed by World Bank 3,357,609 SHSs established until October, 2014, and the numbers increase intensely present in figure (2-13). The capacity achieved by SHS about 150 MW in the year 2013-2014, and growth rate

increases about 185 % from the previous year. In 2015 the growth rate increases to 300 % and capacity raised 234 MW electricity generation potential from SHSs [35]. Generally, distance between SHS about 2-2.5 meter, where most of the system capacity configured with 60 W_p. As shown in figure (2-13), SHS program promoted to increases more than 3.7 million by May 2015 [67], about 98 % of SHS installed through IDCOL [68], and additional 70,000 SHS being installed every month, and targeting more than 6 million more SHS by 2016 [69].

2.4 Innovation Approach for RE

To achieved the Millennium Development Goals (MDG), electrification across nationwide is one of the main topology widely believed contribution, renewable sources deploy to sustainable development which leads to improvement of environment and fosters of socio-economic life. In the modern time, only 11 % of people have the access electricity in the Sub-Saharan countries [70], whereas in Bangladesh about 40 % of households have the access electricity [71], and the improvement rate of electricity through SHS system and bottom-up swarm electrification successfully experienced in Bangladesh past decades. The households and communities are far away from the main grid and grid extension are not always cost effective due to infrastructure and insufficient power supply.

According to authors' of [72] suggested, DC-MG configured by several distributed generation such as SHS and from the local grid that might be connected to the main. A mini-grid can be configured by local distributed generation system and the distributed generation sources' considering along with renewable resources such as PV, biomass, the wind. According to swarm electrification concept, neighbouring households are assimilating in an intelligent network where scheme allows to share their information about supply, demand, and battery status within. To achieve this network by sharing electricity among participants within the scheme, consequently swarm network has the ability to integrate with legacy based where participants have the ability to produce electricity and consumption simultaneously, in order to propagate without or with

limited number single centralized unit which has the ability to function independently may be called nano-grid.

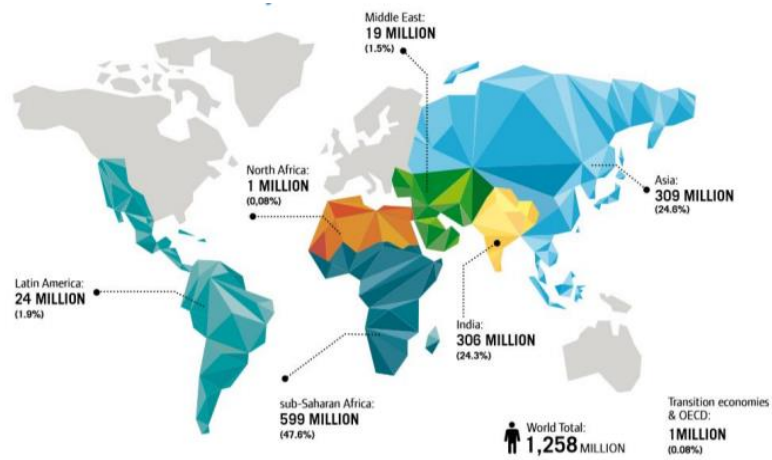


Figure 2-14: World wide electricity access through Rural Electrification [73]

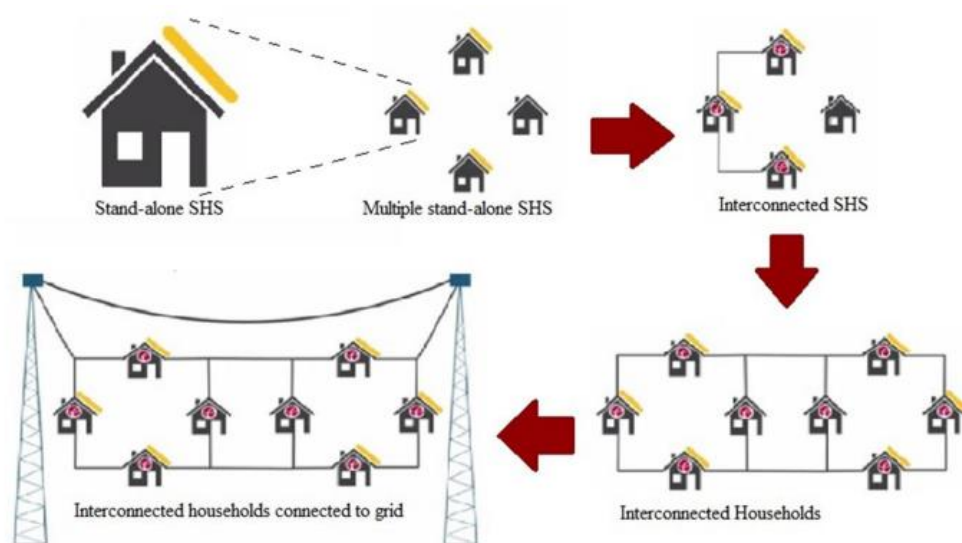


Figure 2-15: Swarm Electrification concept stepwise approaches [74]

In (figure 2-15) represents the swarm concept, where the scheme developed by integrating several SHS and BHS¹ (SHS and BHS characteristics and configuration details in chapter 3 and modelling simulation in chapter 4). It is observed that a sunny day a SHS

¹ Battery Home System configures with battery controlled by charge controller that connected to loads, the surplus electricity from neighborhood SHS available within the swarm network.

in Bangladesh does not utilize their own capacity respect to their loads connected within the system, and 30 % of surplus electricity available for others [75]. Tier based Swarm concept explain in figure (2-15) and (2-16), tier-1 represents a SHS configuration and the loads consumption, self-generated electricity from PV panel. Tier-2 and tier-3 countenance SHS and BHS connected and formed a DC cluster, and tier-4 cluster grid also allow to connect to the grid to sellback surplus electricity. The major strategies for rural electrification to access electricity for all, some studies expressed only about 30 % of rural areas electrified by the centralized grid, whereas 70 % of people can be electrified by the small scale nanogrid or MG [76].

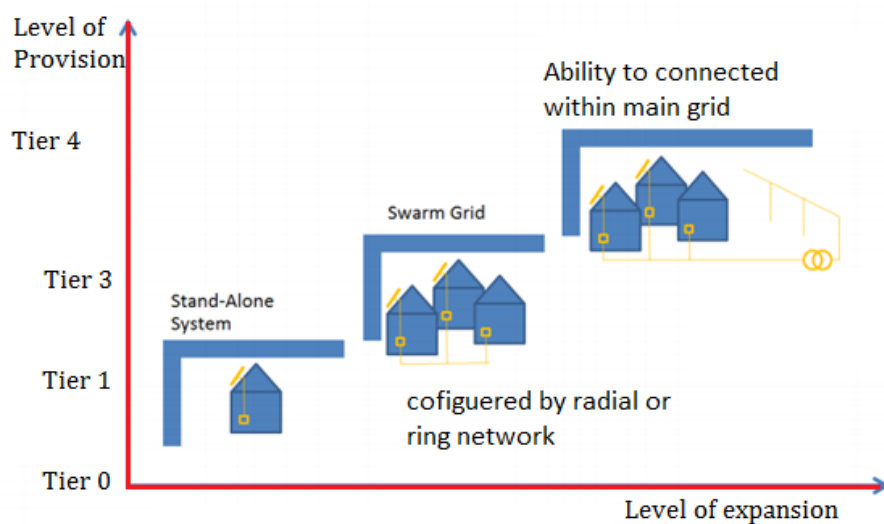


Figure 2-16: Schematic Layout of Tier based Swarm electrification

2.5 Reforms and policies towards Renewable Energy

Declining the fossil fuel along with natural gas, the electricity production reduces whereas demand increases day by day. GOB has restricted and privatized the electricity generation sector by National Energy policy (NEP) in 1996. The major target of the policy to increase the power generation to meet the desires present and future demand which adopted by following policies:

- I. Harnessing solar potential, and dissemination of RET in both urban and rural areas
- II. Enable and encourage facilitate public and private sector investment towards RE projects

- III. Development of sustainable energy system to substitute non-renewable sources
- IV. Facilitating renewable energy at every level of energy including households to commercial and industrial

The national Energy Plan (NEP) envisions 5 % of total renewable generation from renewable sources, and by 2020 achieved by 10 % energy from renewable. Bangladesh Power Development Board (BPDB) imposed the bulk tariff for electricity consumption for distribution companies including Dhaka Electric Supply Company (DESCO), Dhaka Electric Supply Authority (DESA), West Zone Power Distribution Company (WZPDC), Dhaka Power Distribution Company (DPDC), and Bangladesh Rural Electrification Board (BREB). The distribution companies are working in the urban areas and REB with 77 rural electric cooperatives Palli Bidyut Samity (PBS) working for electrification in villages and remote areas.

Summary

It is clear that most of countries including low income and developing countries GDP affected by level of energy consumption, and per capita 0.23 % GDP increases by consuming 1 % of per capita energy consumption. The growth rate of electricity has increased at 5.5 % in the FY 2006-2007, which rapidly increased to about 13.2 % in the fiscal year 2012-2013. Likewise, the GDP of Bangladesh has increased at 6.8 % in the FY 2012-2013 whereas in FY 2006-2007 the rate was just over fraction of 6 %.

Bangladesh is the fast growing developing country, socio-economic, industrialization, other development booming while demand of electricity increases day by day. Currently, power sector of Bangladesh produces 10,445 MW by 2012, different government entities with non-government company working together to meet the electricity demand. Almost 72.42 % of total electricity generated from natural gas in FY 2013-2014, and on the other side, the renewable penetration only about 2.5 % which is insignificant comparison to global power generation. Although, Bangladesh is one of the market leader for SHS, and PV system. In Bangladesh average 4 to 6.5 kWh/m² solar irradiation, and Maximum amount of solar radiation is available almost each month except December and January,

however 300 high sunny days suggested solar generated system like standalone PV system, and SHS. IDCOL and other 47 partner organizations (POs), NGO working together to installing 3 million SHSs by 2013 and targeting almost 7 million by mid of 2018.

Electrical power plays important role among all developing and industrialized countries, advancement of socio-economic conditions depends on per capita electrical power consumption. There are lots of crisis in present days, without solve electricity access, it is impossible to minimize the crisis. Although natural gas reserve sufficiently not enough to cope up the power generation, as demand cannot meet by the existing generation. By using renewable energy sources like PV, Biomass, and other available sources; and modern forms of power system deployment can be solved the crisis. Conventional power system is expensive to configure and present demand is lagging behind from the continuous power supply to electrification, especially for electrifying rural and remote areas. Notwithstanding, the conventional trends to generates electrical power from the top-down grid, and author convinced to follow up the concept of bottom up swarm electrification would be the best solution for electrifying rural areas in developing countries. A robust grid can be formed amongst hybrid power system which configures with integrating distributed renewable sources and back up diesel generator that highly efficient and reliable in the remote areas.

Currently, 55.41 % of rural areas electrified by REB and cooperative organization PBS, whereas 5.05 million households connected to the grid. Yet 45 % of rural areas not electrified by REB which government owned company, but IDCOL and others POs working together to achieve Millennium Development Goad (MDG) and "Vision 2021" simultaneously, about 94 % households decreases about 1.7 litres of fuel (kerosene) consumptions compare to those not connected to the grid, average 90,000 households connected to the grid. During summer the number of new households slightly increased to 300,000, and to achieve 100 % of electrification about 450,000 new households need to connect to the grid by 2018. By the successful SHS program along other biomass integration, and enrichment of electric power generation Bangladesh has achieved almost 11,000 MW electricity by 2014, but still 40 % of population living without access to electricity.

Chapter 3

Stand-alone PV System and Microgrid Configuration

“I’d put my money on the sun and solar energy, what a source of power! Hope we don’t have to wait until oil and coal run out before we tackle that”

[Thomas Edison, 1931]

Introduction

Energy access in any country or region is a fundamental and significant beginning for social and economic development. A country like Bangladesh where energy and power generation is not enough in proportion to the demand. According to the [77], about 45 % to 50 % energy access limited in Bangladesh, and those who have the access that does not sufficiently enough to meet 60 % of their demand. The shortage of demand causes about 5 to 6 h load shedding during summer season per day. A delimited renewable energy integrated network such as nanogrid, minigrid, and microgrid are proposed to an alternative power system for rural electrification. In the chapter, the required elements of an MG, and their basic operation have been described and an optimal design can be fit for the proposed MG. Increasing the opportunity of renewable energy deployment in Bangladesh would be the solution for sources of energy access in the present, and integration of those distributed energy renewable sources (DERs) with the existing system for the proposed future opportunity. The MG can be developed encompasses with small scaled energy network, which included loads like household, community based commercial loads, and a set of DERs, such as solar PV, the wind, energy storage devices, and generators fueled by either conventional fuel or biomass. An MG configured with some smart rudiments that control and regulate to responds demand, which adopted with some smart strategy that enables the prevalent of DERs and fortified with some intelligent devices for protection [78]. According to [79] a small scale MG configured with 100 kW and [80] a micro-generation is measured with smaller scale no more than 3 kW electrical energy and 30 kW thermal energy by adopting cogeneration methodology technology, and conferring the authors of [81]. The tri-generation is one of the most viable forms of poly-generation; energy conversion process with combined heat, cooling, and electrical power, whereas EU restricts the micro-generation up to 50 kW on different schemes and residential scales. Despite the fact, authors of [82] cogitate smaller than 500 kW, while authors of [83] energy generators and DERs should scaling the similar capacity and size as the loads attached in the system and positioned close to the end-users. In this chapter, MG prospects and involved well-suitable components as well as suitable energy sources and technical option for integration of renewable integration to determinate energy access in Bangladesh.

A successful arrangement of MG depends on local distributed energy resources, the capacity of sizing, operational strategy. The local network collaborates with other MG mechanisms that deliver supply to sufficient power to comply demand and higher efficiency. The MG is applicable for single consumer with low demand to medium demand remote off-grid system, campus to community based MG, and utility bases MG with different local RES on the utility side with consumer interaction. Rural electrification functional MG configures with small size, as the system is not able to respond to sudden loads. Hence, energy storage device such as batteries are the essential components in the MG, especially the circumstances when the intermittent source like PV included in the system.

3.1 Concept of Microgrid (MG)

The MG configured with small-scale self-sufficient medium or low voltage network, which generated power from the local resources and supplied to the local consumers. The distributed energy resources (DER) constructed with DG technologies, controllable distributed storage system (DSS), and controllable-clustered loads. Integration of MG that describes the act of combining a couple of energy generation resources work together effectively[84]. An integrated MG system suggests the fact of adjoining operation strategy and control tactic, low or medium voltage distribution system operate effectively and efficiently. For the reliable and stable system, an effective control strategy, coordinated operation, and coupling DERs into the MG [85]. In Bangladesh about 40 % of people does not have electricity access from the main grid which representing 65 million people [86]. The grid-based energy access in Bangladesh, the government has the vision to integrate renewable energy sources share about 5 % of total generation by 2015. The total grid based configuration, about 500 MW of power generation from renewable sources by 2015 and 10 % of total power generation about 2,000 MW by 2020 [87]. The average 5 kWh/m² solar irradiation deteriorating over 300 days per year and an average range of 8 h-10 h sunlight hours offer a best possible solution for energy access in Bangladesh by amassing standalone SHS [[88]. The typical SHS in Bangladesh consist of 20 to 85 W_P of

PV module, battery and charge controller [89]. SHS integrated MG present in figure (3-1), which also have the ability to tie with main grid.

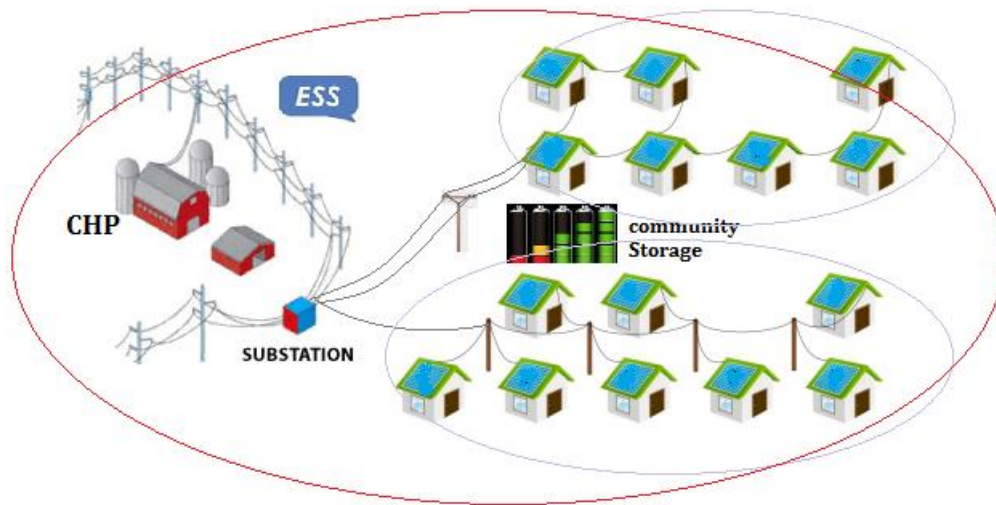


Figure 3-1: Neighbourhoods SHS integrated Micro grid

According to Department of Energy, US [90]:

“a group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.”

Zhang et al. [91] define as:

“A cluster of loads and relatively small energy sources operating as a single controllable power network to supply the local energy needs.”

According to Author:

“An autonomous microgrid considered as integrated system where distributed small scaled energy generation participants associated with community-based generation and storage can be shared their energy each other”

3.1.1 Key components of Micro grid and Configuration

The MG configures with distributed renewable energy sources, power level and conversion devices, controllers, Energy Storage system, energy management system, and communication system for controlling and protection [92]. The foremost advantage of MG, they have the capability to operate seamlessly which isolated from national grid without disruption to its load. The end-users including consumers and prosumers is another key component of the MG. Affording the best usage of local RES, DC loads, and micro sources like SHS sharing their excess energy among within the LV network. The RE sources operation strategy, controller scheme with exchange power with another network like national grid and end-users. Typically an interconnection of DGs, either set of generating units such as diesel generator or gas generators and fuel cells or non-dispatchable generators such as wind generators, Photovoltaic units, electrical energy storage that meet customers demand discussed in [93], describes bellow;

- Distributed Controllers in SHS and other micro sources control voltage and current level.
- Power conversion device such as DC-DC converter, pole-mount transformer control their voltage level and power quality of MG. PV produce DC voltage, biomass fueled CHP micro turbine produce AC voltage with different amplitude, Power electronic converter interface solved the problem [94].
- Communication system used in the MG system for monitoring and control the system respect to setting data [95].
- EMS is the strategy for device control. Also, function for future power prediction from renewable energy, power planning, and load forecasting.
- Micro source like CHP generated biomass driven electricity unit and this dispatchable source is non-controllable. Primarily gas fired biomass source one of the important source of energy in the micro grid.

3.2 Combined Heat and Power (CHP)

Decentralized power generation with biomass fuel CHP is an important source of electricity for improving energy efficiency, energy security and emission of CO₂. Combined heat and power (CHP), is a co-generation technology that simultaneously generate electricity and heat. By using absorption chiller, the heat has converted into cooling for cold storage. A biomass-fueled cogeneration unit has to consider and specified in the terms of thermal rather electrical. There are many commercial CHP deliver heat to electricity ratio of 2:1, even down to 1:1; with organic ranking cycle can be possible as 5:1 [96]. By CHP technology always offer heat generation accompany electricity co-generation and suitable load complies during all operation including standalone and grid tied. According to offline optimization approach, minimize the energy cost and emission by integrated PV array, wind turbine, and CHP in the MG described in [97].

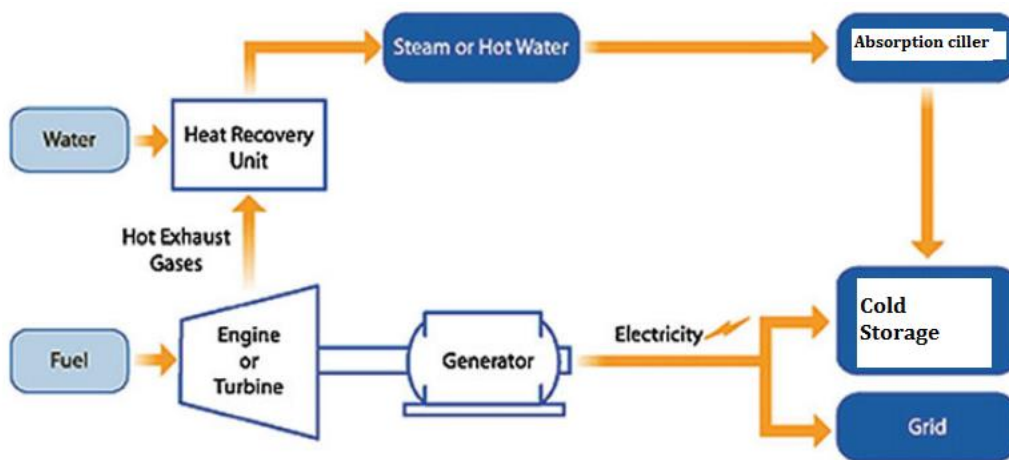


Figure 3-2: Micro-CHP technology and components [98]

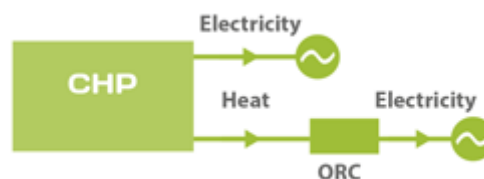


Figure 3-3: ORC in CHP enhancing electricity generation [99]

Today, CHP technology with excellent efficiency and better electrical output also adopted in the small-scale system. The micro combined heat and power micro-CHP describes all electrical power generation systems that utilize recoverable waste heat converted through absorption chiller for cooling. The range of micro-CHP from 10-30 kW or less, electricity generated on site from the combustion of biomass fuel source in an electrical generation set including the prime mover and generator. The excess thermal energy from micro-CHP converted into the cooling air for cold storage, cooling purpose increase the overall energy efficiency usage. A cogeneration CHP system or CCHP (Combined Cooling and Heat Power) consists of prime over, generator convert to electricity, heat recovery system, and absorption chiller convert to cool air, control system shown in figure (3-2). Heat released form Biomass combustion and used to produce steam can drive the steam turbine. In the micro-scaled biomass-fuelled CHP, biomass conversion technology has three choices for prime mover such as; gas turbine, internal combustion, and fuel cells [100]. In part-load conditions, the surplus energy including electricity and heat may sell to the grid and community. The electricity produces by congregating unit μ -CHP which located on site or distributed through AC or DC bus that delivers electricity to the loads through to grid or directly to loads without the grid. A load of thermal energy usually positioned on site. The advantage of the μ -CHP system has the ability to improve both electrical and thermal efficiency by use of fuel. However, the system requires total fuel to produces both electrical power and thermal power in a cooperation system is less than the total fuel involves producing same amount of electrical power and thermal power. The efficiency of fuel used in the μ -CHP system that transmuting fuel into thermal defined by (EFTHE) express in the (equation 3.1), that described by the first law of thermodynamics is the ratio of net energy output QH and divided by the fuel consumed (QF). The range of standard efficiency in the typical m-CHP 65 % fuelled by biomass. Power generated by the m-CHP, efficiency of fuel transforming electrical power (EFTEE) shown in (equation-3.2) and define by the ratio of electric energy and the amount of fuel consumption (QF); the heat energy transferred into electrical energy done by mechanical work (WM). The standard range of electrical efficiencies in the typical m-CHP found from the studies about 33 to 35 % [101].

$$EFT_{HE} = \frac{Q_H \text{ (kWh)}}{Q_F \text{ (kWh)}} \quad 3-1$$

$$EET_{EE} = \frac{E}{Q_F} = \frac{Q_H Q_M E}{Q_F Q_N W_M} \quad 3-2$$

3.2.1 Proposed Micro CHP

A biomass-based boiler may have deployed as renewable energy based heating source, where hot water at temperature 100 °C to 140 °C supplied at ORC evaporator level to evaporate the organic fluid and at a temperature of 60 °C to 80 °C to desiccant generation to regenerate the weak liquid desiccant. The proposed tri-generation have the ability to provide electricity, heating, and cooling[102], and Organic Ranking Cycle (ORC) based tri-generation have been widely used in electric power generation from low temperature heat sources [103]. Biomass fuel fired CHP, where electric power generation 10 kW, which has a great potential to meets the community based energy both electricity, and cooling demand. Sometimes OCR cycle based engines not considered where CHP system has relatively low electrical conversion efficiency. Yet, electrical efficiency comes to be considered less important issue where the proposed micro-CHP due to simple design, low costs, favourable operation, durability, and high performance in community cooling system or cold storage facility [103]. This proposed system considered with two cycles including hot water cycle heated by the biomass boiler and ORC cycle. The heat releasing from biomass combustion inside the boiler through heat exchanger, the hot water use follows ORC working principle to heat into vapour in the evaporator. The generated organic vapour drives the expander² wheel in the evaporator of the system. The expander should be adaptable within the ORC system that utilize small gas turbine as thermal source of energy to generate 2 to 10 kW of electricity [104]. The CHP with 50 % heat recovery and about 80 % electrical efficiency configured with ORC based output present in (figure 3-3). The ORC working fluid at expander exhaust releases some heat through the recuperator, and pumped back to the evaporator. The cooling water from the condenser is heated and used to clean the cold storage weekly. The proposed CHP might have above 80 % of electrical efficiency [105].

² The expander wheel is a module in a turbine that rotate by the steam or vapor, the prime mover rotate coupling with the module and generate electricity through the electric generator.

The conversion of final energy that generated by the micro-CHP, the energy efficiency factor (EEF) defined by the equation (3.3)

$$EEF = \left[\frac{E_u}{E_p} \right] \times 100 \% \quad 3-3$$

Where,

E_u = Useful Energy

E_p = Primary Energy

3.2.2 Micro Turbine (MT)

The MT is consisting of four major elements such as; turbine that transform pressure of hot steam or gas, alternators that generates electricity, compressor that compresses inlet air to high pressures, combustor that combustion begin between heated compressed air and fuel mixed and burned which is from biomass, recuperate that exchange the heat for transferring heat from exhaust gas to air before it enters into the combustor described in [106] - [107]. In CHP, the MT is the backbone of the system that produces electricity and heat converted through absorption chiller produce cooling air for cold storage. The MT has the advantage such as high power density, lighter weight than another turbine, clean emissions, fuel flexibility, low vibration and low maintenance, high reliability and high durability [108]. The process of a micro turbine is similar to a gas turbine, which has a heat recovery unit (recuperator) that exhaust heat and use preheat the combustion air, that heat from the turbine exhaust to preheat the intake air, raising the turbine's internal temperature [109]. The recuperator act as radiator or heat exchanger that transfer heat from exhaust to the incoming air. As the system mainly used for electricity and Colling, the recuperator is important parts for the micro-turbine, an "intercoolers" preferred to design in the system; porcelain disk with holes that allow airflow through the system enlightened in Allison type micro generator[109]. Nevertheless, non-recuperative turbine generates electricity from gas with an efficiency 15 %. Most of the turbine configured with the rotation speed of 90,000 -120,000 rpm [101].

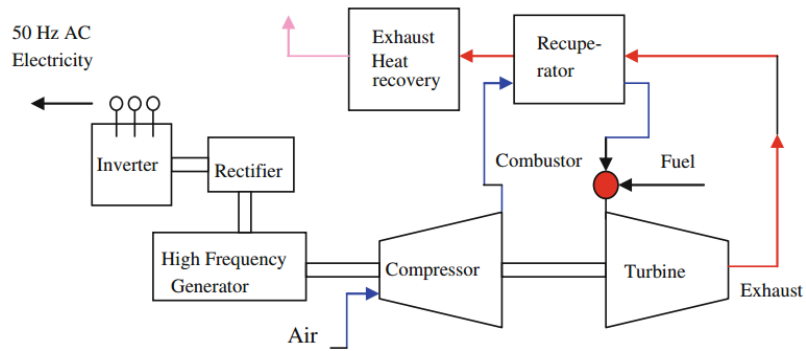


Figure 3-4: Schematic diagram of a single shaft micro turbine [110]

The nominal rpm speed does not depend on the capacity; the rpm depends on the manufacturer. The small-scaled micro-turbine rotational optimum speed rated at 40,000 to 90,000 rpm and pressure ratio of 4:1 in the single stage. For small scale CHP, micro turbine configured with the electric generator either synchronous or permanent magnet, or a group of redresser-converter that supports adaptation to adapt electric charges to the grid. For the fast and faultless dynamic controlling including starting, shutting down and other speed control described in the model described in figure (3-4). The MT based CHP operates in the MG, which not only produces electricity but also heat that convert into cool air by using thermal driven chilling absorption module. The advantage and disadvantage of micro CHP bellow present in the table:

Table 3-1: Micro CHP advantages and disadvantages

Advantages	Disadvantage
<ul style="list-style-type: none"> • High reliability and durability • Low emission • No external equipment required for cooling 	<ul style="list-style-type: none"> • High pressure required for • Poor efficiency at low loading • Output drops as ambient temperature raise

3.2.3 CHP fuel

Direct combustion from the available living and living organisms considered as biomass fuel used to harness energy. Biomass combustion has 68 % to 79 % efficiency depending on fuel moisture content, and combustor design, and combustion operation [111]. There are many types of fuel and sources for the micro CHP that produce heat and electricity such as; biomass, solar thermal, natural gas, LFG (liquid fuel gas), and hydrogen. The community food waste, crops, leaves, and animal manure to generate biogas that landfill avoided which reduces methane potential damage the atmosphere [112]. By using this waste from the project location, and utilizing these by CHP in the community to deliver electricity and cooling. The following section author will be discussed the potential of biomass in the location where CHP and MG under consideration.

3.2.3.1 Biomass Potential from Plantations

According to RED (renewable energy directive); “biomass is the biodegradable fraction differ from waste product to food waste, biological origin to animal substances, agricultural crops to vegetable and community and animal manure” that deliver electricity and heat from biomass. Processing of biomass assure no loss during the long-term process of biomass [113]. Initially about 20 % of moisture reduced from the biomass contents, as a small space required to densified biomass contents [114].

3.2.3.2 Field trip Data Collection

The data collection regarding available average biomass opportunity for generating electricity in Gopalgong in Bangladesh.

- To investigate the possible location of the MG system
- Consideration: mapping the areas for agricultural crops, total number of population, household, and animals.

The assessment to evaluate the recent and future biomass energy resources and biomass waste production from all kinds of local available biomass resources such as; organic materials from living or dead organisms.

Biomass Potential from source of Agriculture

From the plantation of the local residues mainly from rice, jutes, sugar cane, coconut are available for electricity production. Among field crops, household's areas' have the control of plantation. Local cows in Bangladesh produced 10 kg/day (khan, et al). According to persistence, the available average biomass from these tree plantation as followed in the (table 3-2).

Biomass Potential from Animals and others sources

Cattle, goats, buffaloes, sheep, pouty and human manure are the general sources of biomass energy. According to the data have collected 80 households are where approximately 250 people, 200 cattle's, 350 goats, 200 buffaloes and sheep. From the two poultry and other individual households has 3000 ducks and chicken. The biomass potential from animal waste calculation bellow table (3-3)

Table 3-2: Agriculture based biomass potential [115]

Crops	Rice	Jutes	Sugarcane	Coconut	Others ³	
Production (tons/year)	18.5	12	5	0.2	0.1	
Fractions	Husk	straw	Stalk	Bagasse	Shell	
Amount in fractions [%]	100	40	58.84	36.0	24.4	13.91
Crops reside [tons/year]	15.115	10.2	6.707	1.44	0.049	0.00139
Average [tons/day]	0.07	0.018	0.008	0.00013	0.00003	

Total agricultural based biomass = 0.0961 tons/day

Table 3-3: Biomass production from Animal waste [115]

Livestock	Cattle	Buffalo & sheep	Goat	Poultry
-----------	--------	-----------------	------	---------

³ Others agricultural based biomass consist of tree branches, dry leaves, woods

Biomass (kg/animal/day)	2.86	2.54	0.55	0.18
Biomass production (kg/day)	572	508	192.5	540

Total biomass production = 1.81 tons/day

According to determination, the available average biomass from these animal waste and other sources available in location site as followed in the (table 3-4)

Table 3-4: Total biomass available from biomass waste

Materials	Biomass production (kg/head/day)	Biomass production
Livestock	-	1.81 tons/day
Human manure	0.40	0.100 tons/day
Rural solid	0.15	.03 tons/day

Total biomass production = 1.94 tons/day

Total biomass production

Approximately 60 % of Agricultural residues, 30 % of animal waste and poultry and 10 % of others average biomass production.

The average biomass production = 2.04 tons/day. The available average biomass depends on the local site and the production depends on total production of agricultural crops, vegetable, and agricultural other production which also based on geographical location, temperatures, rainfall, and climate. The agricultural crops including rice, vegetable, pulses grown mostly in the winter rather than in summer. The monthly average based Biomass volume (tons/day) production are changing over a year bellow.

Table 3-5: Average Biomass Production

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
2.04	2.04	1.90	1.85	1.80	1.80	1.80	1.95	1.95	1.95	2.0	2.048

3.2.3 Cold Storage Design

The basic refrigeration or cooling cycle includes a refrigerant that undergoes phase changes in which it absorbs heat or rejects heat. In the traditional refrigeration system, a compressor which is located in the cold storage that reject the heat [116]. The Cold storage gives up the heat, which is from the foods kept inside the cold storage that transfers the heat to heat rejection device such as absorption chiller (describe in the next section 3.2.4). After study and gathered knowledge about Cannington cold storage [112] and [117] A cold storage consisting of couple of components such as;

- An evaporator: two phase coiled tube used for heat exchange
- An absorber: two phase coiled tube mass and heat exchanger
- Two regenerators including high temperature and intermediate temperature and two phase boiling coil
- A condenser: heat exchanger from micro-turbine back to boiler
- Three pumps: a sorbent pump, a refrigerant pump, and chilled water pump
- A Fan: circulating cool air all over the cold storage
- The cooling capacity of the cold storage or chiller load

$$Q_{\text{cold-storage}} = m_{\text{cw}} \times C_P \times (T_{\text{CWE}} - T_{\text{CWL}}) \quad 3-4$$

Where,

m_{cw} = Chilled water flow rate

C_P = Specific heat of water

T_{CWE} = Temperature of chilled water entering into the chiller

T_{CWL} = Temperature of chilled water leaving form the chiller

Coefficient of Performance of Chiller

$\text{COP}_{\text{thermal}} = Q_{\text{cooling}} / Q_{\text{heat}}$

$Q_{\text{heat}} = M_{\text{steam}} \times (H_{\text{steam}} - H_{\text{condensate}})$

Heat delivered to the chiller by the system

Where,

M_{steam} = Flow rate of Steamer

H_{steam} = Enthalpie of steam supply

H_{conden} = Enthalpie of condensate supply

3.2.4 Absorption Chiller

Absorption chiller is mechanical contraption that driven by heat and produce chilled water for cold storage and another form of the facility as required. There is no mechanical energy consumed in the absorption chiller, an absorption cycle which is similar to vapor compression cycle deepening on chemical affinity of absorbent for chilling or refrigerant to improve cooling effect [118]. The chiller produces chilled water by removing heat from cold storage and transfer the heat to the evaporator. For refrigeration, water is used for refrigerant and bromide is used for absorbent [119]. In the absorption chiller great variety of hot media or material can be used; such as LiBr (Lithium Bromide), ammonia-water ($\text{NH}_3 - \text{H}_2\text{O}$) [120]. One stage cycle used in vapor compression, where ammonia-water used and two stage cycle used lithium bromide shown in figure (3-5). The absorption chiller consumes heat which supplied by CHP, and chiller also rejects same amount of heat.

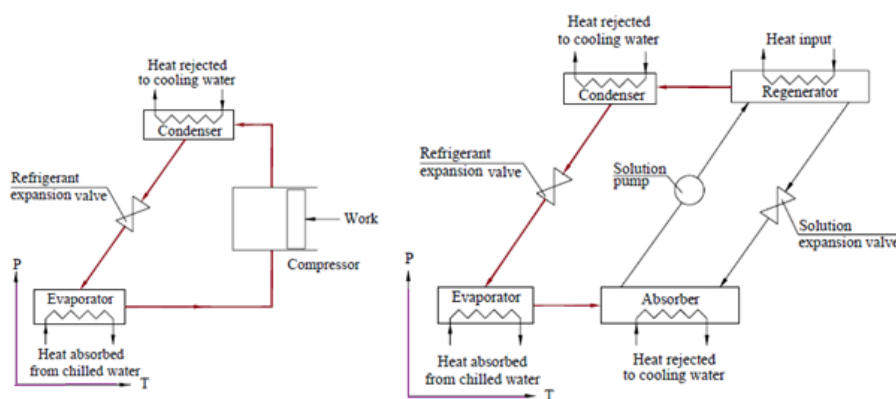


Figure 3-5: Absorption Chiller cycle (Left) & Vapour compression cycle (right)

3.3 PV panel Design and modelling

3.3.1 Solar Cell and PV Module concept

Solar energy (Photon) strikes onto the solar cell (semiconductor materials) electrons knocked loose from the atoms and producing hole-electron pairs (Lorenzo, 1994). As forming an electrical circuit by assigned an electrical conductor to the positive and negative sides the electrons are captured and form electric current I_{ph} (photocurrent) of the cell. According to Lorenzo; one diode model of a solar cell; in darkness (no solar irradiance), cell not active and works as diode produce neither voltage nor current. Nevertheless, cell connected to an external supply it generates diode current or dark current I_d . A PV cell charges by sunlight, cell produces DC photo-voltage range of 0.5 V to 1.0 V and some 10 mA per cm^2 in short circuit [121].

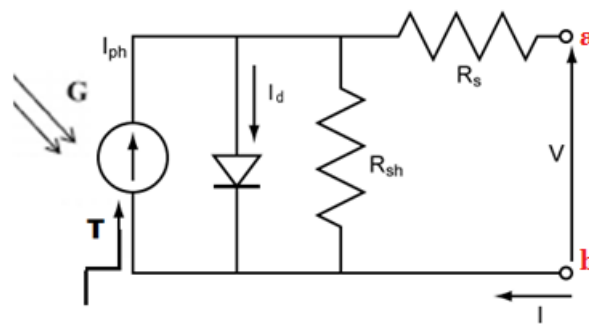


Figure 3-6: Equivalent circuit of PV solar cell

$$I = I_{ph} - I_0 \times \exp\left[\left(\frac{q(V-IR_s)}{AKT_c}\right) - 1\right] - \left[\frac{V + IR_s}{R_{sh}}\right] \quad 3-5$$

$$V = \frac{AKT_c}{q} \ln\left[\frac{I + I_0 + I_{ph}}{I_0}\right] - IR_s \quad 3-6$$

Where,

- I = cell current (A)
- I_d = Diode current (A)
- q = electron charge (1.602×10^{-19} C)
- V = cell output voltage (V)
- T_c = cell temperature (K)

- A = diode Ideality factor
- K = Boltzmann Constant (1.38×10^{-23} J/°k)
- I₀ = Dark saturation current.

A single solar model comprehends a source current, I_a for one diode, a parallel resistance R_P and a series resistance R_S; which represents the resistance of each cell and in the connection between the cells. The net current from the cell is the difference between the photocurrent I_{ph} and diode current I_d of the cell, and express by the equation.

Assume I_{sc} = I_{ph}, the series resistance of solar cell is low and parallel resistance of solar cell is high. Photocurrent of solar cell depends on irradiance G and temperature equation extant in equation (3-7). I₀ is the dark saturation current that is strongly dependent on temperature (Lorenzo, 1994). For adjusting I-V, characteristics of solar cell contingent factors taken into idealizing factor and temperature should be same in both Boltzmann constant K and cell temperature T_c. The voltage of solar array is the number of series connected solar cell in the solar array module multiplies the voltage of single solar cell in equation (3-5) & (3-6). The total current of solar array is the sum of the current drifting through single solar cells in parallel. The current obtained by divided total array current by the number of cell connected in parallel seen in equation (8), which is operative for certain cell temperature T_c and corresponding solar irradiation G [122]. The temperature effect is detail explanation in section (4.1.2).

$$I_{ph} = (I_{ph,ref} + K_I \Delta_T) \frac{G}{G_{ref}} \quad 3-7$$

G: solar irradiance (W/m²), G_{ref}: Irradiance at STC = 1000 W/m², Δ_T = T_C - T_{C,ref} (° K), T_C : Cell temperature at STC=25°C, K_I = Coefficient temperature of short circuit current (A/°K), I_{ph,ref} : Photocurrent at STC.

In practical solar Cells connected, either in parallel increase the current and in series provide greater output voltages. Tangible solar arrays are composed of several connected PV cells and the observation of the V-I characteristics seen in (figure 3-7); (a) The voltage increasing in PV module, the individual cell connected in series as V= V₁+ V₂+... (b) The current in the PV module, individual cell connected in series as I =I₁ + I₂ +...

A PV module is consisting of group of solar cells, in practical solar Cells connected; either in parallel increase the current and in series provide greater output voltages. In the figure, illustrates solar arrays with N_{PM} parallel branches each with N_{SM} Series modules. With the intention of specification of each element in the PV module where parameters with subscript 'M' are referring PV module, while parameter with subscript 'C' are referring solar cell.

The total current and voltage of PV module has presented in an implicit expression depending on following variables articulated bellow in equation (3-8) and (3-9).

$$V_{OC}^M = N_{PM} \times V_{OC}^C \quad 3-8$$

$$I_{SC}^M = N_{SM} \times I_{SC}^C \quad 3-9$$

Where

I_C^M = short circuit current of solar module

I_{SC}^C = short circuit current of solar cell

V_{OC}^M = pen circuit voltage of solar module

V_{OC}^C = short circuit current of solar cell

N_{SM} = number of cell in series

N_{PM} = number of cell in parallel

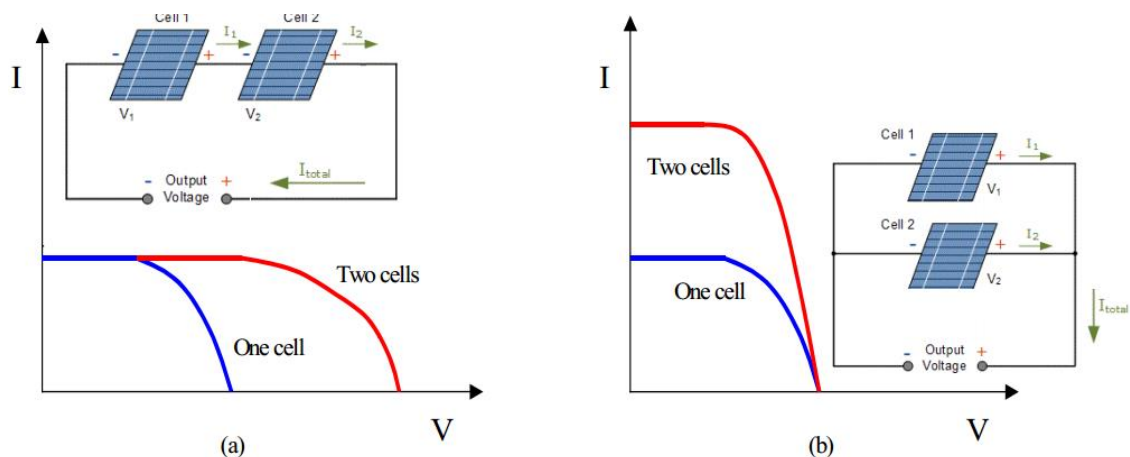


Figure 3-7: Solar cell (a) series connection (b) parallel connection

V-I characteristics of typical solar cell for certain ambient irradiance and certain fixed cell temperature T_c . Solar cells in PV module connected parallel increase current and connected series greater output voltage.

Cell terminals shown in figure (3-6) as terminal “a-b” connected to variable resistance R_S , the operating point determined by the intersection of I-V characteristics of solar cell figure (3-8). For the resistive load, the characteristic is a straight line with a slope $1/V = 1/R$. The power delivered to the load depends on the value of resistance only. When resistance is small, the cell operating point in the region MN of the curve, where cell perform as a constant current source, almost equal to short circuit current (I_{sc}). If, R larger, cell operates in the red marked line in figure (3-8) region of the curve, where cell perform as constant voltage source almost equal to open circuit voltage (V_{oc}).

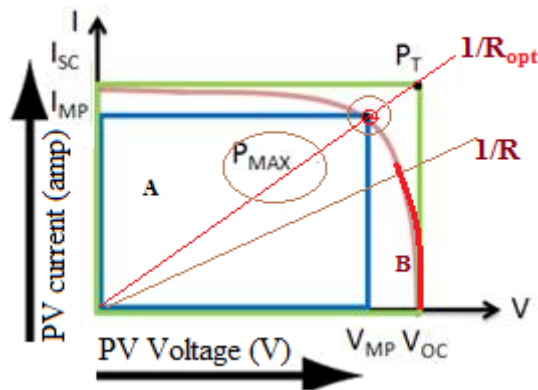


Figure 3-8: V-I Characteristics of Typical Solar Cell

Module current at operating condition

$$I^M = N_{PM} I_{SC}^M \left[1 - \left(V^M - N_{SM} V_{OC}^C + I^M R_S^C \frac{N_{SM}}{N_{PM}} \right) / (N_{SM} V_t^C) \right] \quad 3-10$$

$$V^M = \ln \left[\frac{I_{SC}^M - I^M}{I_{SC}^M} \right] V_t^C + V_{OC}^C - I^M R_S^M \quad 3-11$$

The V-I and P-V characteristics and I curves of solar cell in figure (3-9), the cell operate in constant current source at low operating voltage, other hand the constant voltage source at low operating current.

$$P_{MAX} = V_{MAX} \times I_{MAX} = FF \times V_{OC} \times I_{SC} \quad 3-12$$

$$P^M = V^M \times I^M \quad 3-13$$

Where, V_{MAX} and I_{MAX} are Maximum terminal voltage and current of the PV Array. The maximum power of the open-circuit voltage and short-circuit current are the maximum voltage and current respectively. Determining the maximum power of solar cell, Fill Factor (FF) is important parameter, which is unification with V_{OC} and I_{SC} . Graphically, FF defined as the ratio of area A and B seen in figure (3-8).

$$FF = \frac{A}{B} = \frac{V_{MAX} \times I_{MAX}}{V_{OC} \times I_{SC}} = \frac{P_T}{P_{MAX}} \quad 3-14$$

The quality of the solar cell substantially measures by FF measurement, associating maximum power (P_{MAX}) and theoretical Power capacity (P_T) in figure (3-8).

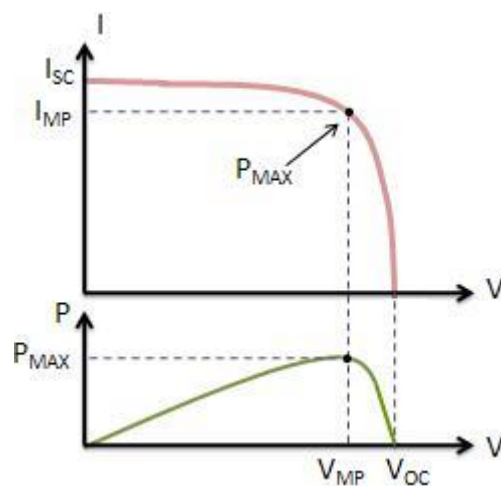


Figure 3-9: V-I & P-V Characteristics curve of solar cell for Maximum Power Point

3.3.2 Temperature dependence

Electricity generation from solar cell depends on operation temperature. Through an increasing the temperature of solar cell while the short current (I_{SC}) marginally increasing and open circuit voltage (V_{OC}) significantly decreasing (about -2.3 mV for each

K) leading to electrical yield reduction ratio of -0.4 % per K to 0.5 % per K for mono and multi-crystalline silicon solar cell [123].

The cell operating temperature varying with the ambient temperature and irradiation level change as a result photo current and output voltage level changing. The operating temperature of solar cell fluctuates varies with ambient temperature and solar irradiation. The variable ambient temperature (temperature of location) T_a affects the cell photon current and cell output voltage. These affects in the solar module by the temperature coefficients K_V of open circuit voltage V_{OC} and temperature coefficients K_I of short-circuit current I_{SC} [124].

$$T_C = T_a + C_2 G_a \quad 3-15$$

$$C_2 = \frac{T_{ref}^c - T_{a,ref}}{G_{a,ref}} \quad 3-16$$

Where, the value of $C_2 = 0.03$ reasonable to approximate. At present time, temperature of Bangladesh is unpredictable almost every hour changes due to climate change. Assuming ambient temperature (T_a) 25°C , whereas cell temperature T_C is directly proportional to the irradiance G_a in equation (15).

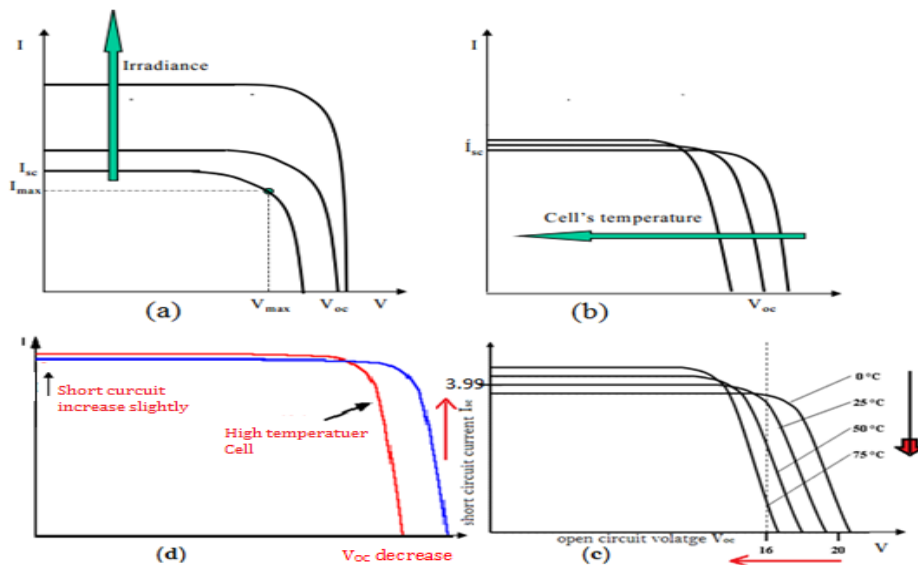


Figure 3-10: V-I Characteristics curve (a) increase short circuit (I_{sc}) respect to solar irradiation (b) I_{sc} & V_{oc} Changes effect with cell temperature (d) precise observation impact on I_{sc} and V_{oc}

3.3.3 Maximum Power point tracking

The optimal output power of PV modules by tracking the maximum power point (MPP) shown in the figure (3-8) and (3-9), maximum power point tracking commonly known as MPPT which tracking P_{MPP} by electronic system that operates in the PV module through automatically find out V_{MPP} or I_{MPP} and achieve P_{MPP} under variable temperature and solar insolation [125]. The variation of atmospheric parameters (T_a , G_a) the fractional ISC and VOC changes, as the matter of fact I_{MPP} and V_{MPP} is linearly related to the I_{SC} and V_{OC} of the solar module respectively in shown equation (3-17) and (3-18);

$$I_{MPP} = K_1 \times I_{SC} \quad 3-17$$

$$V_{MPP} = K_2 \times V_{OC} \quad 3-18$$

Where K_1 and K_2 are proportionality constant, the approximate value of K_1 found between 0.78 and 0.92, and value of K_2 between 0.71 and 0.78 [126].

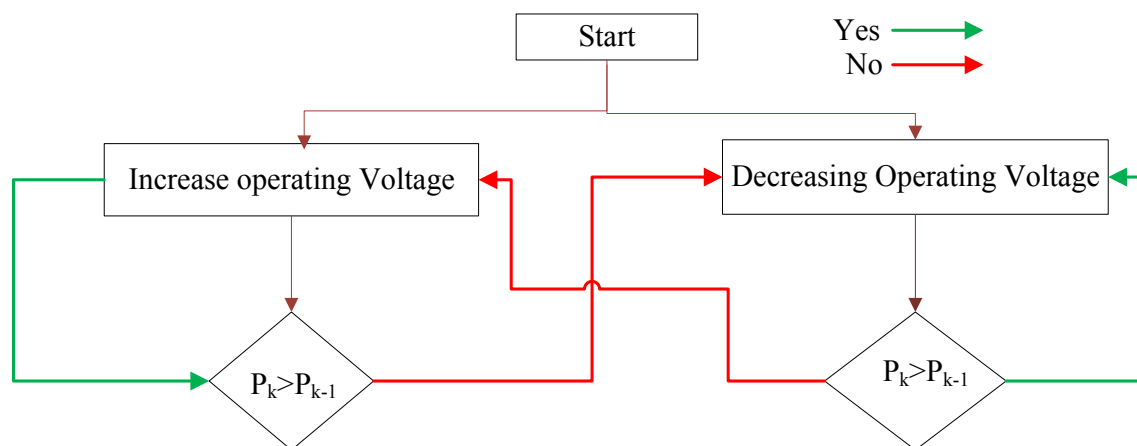


Figure 3-11: Flowchart display for Perturbation & observation algorithm

Technically and economically feasible is to choose MPPT used between the solar array and load to utilize available solar maximum power and matching impedance of the load. Generally, MPPT is the electronic control based particular tracking algorithm. Tracking the maximum power of solar cell following equation (3-11) from a solar cell or solar module MPPT algorithm used and increase the efficiency of the cell. The maximum power

Point (MPP) extent on ambient temperature, irradiance, and load. There are various methods obtainable such as Perturb & Observe (P & O) method, incremental conductance method, constant current method, constant voltage method, method, Fuzzy logic etc. Among all methods this P & O are commonly used, the flowchart bellow presents the simplified method of P & O present in figure (3-11).

Relatively holding constant current based and voltage varied for different resistive load in the SHS circuit. In PV module both voltages varying according to its V-I characteristics, and resistive load considered as $V=IR$ (V = terminal voltage, I = current, and R = resistive load). By studying and observing the PV model output of PV array in Simulink based environment observed; the consideration of maximum solar insolation on point for high load resistance the circuit operate at high voltage but current constant and power is high. Likewise, if the load resistance is small the circuit operate at low voltage but the current is high the power is low. As all most, every load in the SHS are in parallel and require a fixed voltage, so a battery used to constant voltage as well as to deliver power during the solar panel is not generating power. The SHS and DC bus set at the battery operating voltage, that reference voltage force to operate the system (explained in the chapter-4).

3.4 Solar Home System Design and Configuration

3.4.1 Concept of SHS Design

In order to Energy Access with a renewable powered hybrid system for sustainable development depicted in figure (3-12). The Range of SHS power depends on

- Solar panel peak power (W_P)
- Capacity of energy storage system (battery capacity (Ah))
- Load and consumption characteristics and range.

The ratio of lead acid battery capacity and solar capacity Ah/W_P range from 0.9 to 1.5 depending on a number of Autonomy SHS. The Solar Capacity ranges from $45 W_P$ to $65 W_P$ and design considering no critical such as CFL or LED light, TV, radio, ceiling fan, mobile charger detailed in load section. According to the Author of this thesis SHS design and defined as;

“Source of energy generation from the Solar panel (45 WP to 65 WP), store energy in Lead Acid battery rated at 12 V, 60 Ah. The charge controller in the system between the battery and domestic load, and operate as the controller. The system design with 12 V, SHSs connected each other with 230 V with the grid-tied condition.”

Operation of SHS in standalone mode or tied within MG:

- Individual SHS independent
- Share energy along with other SHS and BHS
- Grid-tied with all SHS and BHS
- Grid-tied with SHS with BHS

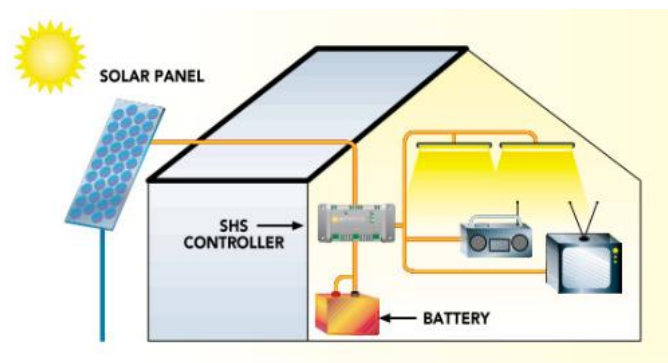


Figure 3-12: Typical Solar Home System diagram, (Courtesy Morningstar Corporation)

Particularly in the sunny and tropical country like Bangladesh, solar PV the most preferred renewable energy source to electrifying the nation. The most attractive part of SHS is PV panel easy installation, no maintenance, and easy to incorporate into the home system. An SHS defined as a standalone system integrated with PV panel, Battery, charge controller/regulator, and low powered loads are shown in figure (3-12). Its basic concept is to utilize the solar power convert into electricity and supply to the household appliances, and excess energy can be stored in the battery. The goal of energy access in Bangladesh to comply the “vision 2020”, rural electrification is the important factor. Along within this goal increasing the number of standalone SHS, grid tied SHS nano-grid and the centralized MG would be the best solution for electrifying Bangladesh. Traditional houses offer rooftop PV system to the houses for home usage[127]. The System designed as DC; the power generation from rooftop PV panel to charge battery and supply to the

loads. In general, the primary and only source of power supply for SHS has PV generated electricity.

3.4.2 PV panel configuration

Afterward having the solar insolation data, design the system determines the demand (electrical load) that the system has to support. The demand estimation is one of the key factor of technical design and cost of standalone SHS.

$$\text{Size of solar panel (W)} = \frac{\text{Total daily load consumption (Wh)}}{\text{daily Sun hour (h)}} \quad 3-19$$

As the system set at 12 V, but the maximum power point of solar does not occur at 12 V. It is typically set at a much higher voltage such as (14 to 24 V) to maintain the power output to 12 V, so there is no problem to charge during less solar isolation or partly cloudy. Predefined 12 V system with solar panel wattage power rating cannot power to 12 V wattage power to load. Such as 65 WP Load at 12 V requires $65 \text{ W} / 12 \text{ V} = 5.4 \text{ A}$ (because $P=V \times I$), typically a 45 WP SHS and 65 WP SHS configures along with PV module which design allow to produce maximum PV current about 3.2 to 3.5 A for regular SHS and 5.42-5.6 A for large SHS.

The size of different constituents of SHS is done according to the system configuration, the consumers (among large SHS, Medium SHS, and BHS) manage their desire energy from grid or Battery, and the battery is connected to the PV panel through the charge controller. However, the consumer's first priority to consume energy from PV, then Battery and if not then grid.

3.4.3 Load Modelling

Profoundly, the load is the driving factor behind any power system, large or small. In a typical SHS, the electric loads are consisting of LED or CFL lights, cell-phone chargers, TV, Ceiling fan. In proposed system, there are three different types of loads categorized in

system configuration; including Large SHS load, Medium SHS Load, and BHS Load. According to the load profile, CFL or LED lights used from 19:00 h to 22:00 h, TV used from 18:00 h to 23:00 h, Mobile charger used in both 9:00 to 11:00 and 20:00 to 22:00, and the ceiling fan used from 22:00 h to 5:00.h The figure (3-13) represents the typical summer load of households in MG in the proposed location.

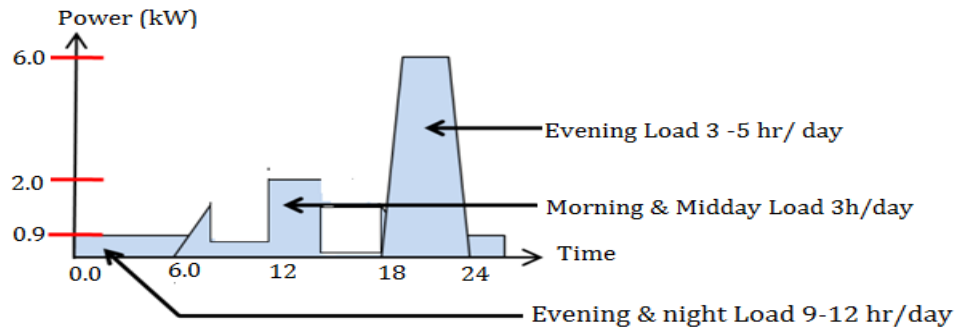


Figure 3-13: Proposed Household Load Profile

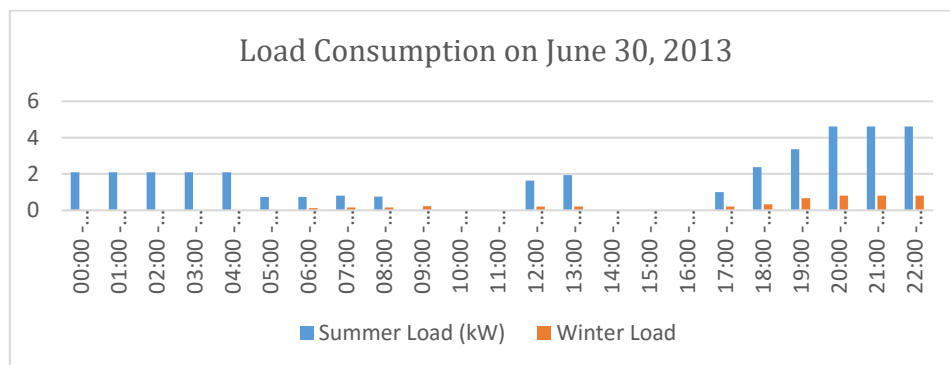


Figure 3-14: Load Profile Consumption

The Loads are various electrical appliances that consuming energy directly or indirectly from Battery. Due to low power requirement for the system considered 12V DC circuit, as increasingly available DC electrical appliances such as LED and CFL lights, Small DC powered TV, mobile charger, and DC ceiling fan connected directly to the system. Each of system load profile modelling has two important characteristics to designing both SHS and BHS, the peak power (in watts) of each load and consuming time duration (in hours). In the figure (3-14) represents, the summer and winter loads by light blue and orange

histograms respectively, it is clear that due to ceiling fan requires high electricity in the summer season.

Table 3-6: Load consumption of typical Large SHS

Appliance	Rated Capacity	Operation (h)		Total energy		Energy consumption	
		Summer	Winter	Summer	Winter	Summer	winter
CFL (4)	6 W	5	5	30	30	120	120
Ceiling fan (3)	60 W	8	0	420	0	1440	0
M. Charger (2)	3 W	3	3	9	9	18	18
TV (1)	20 W	5	5	100	120	100	100
Total energy consummation (kWh/day)						1.1678	0.358

Table 3-7: Load consumption of regular size SHS

Appliance	Rated Capacity	Operation (h)		Total energy		Energy consumption	
		Summer	Winter	Summer	Winter	Summer	winter
CFL (3)	6 W	5	5	30	30	90	90
Ceiling fan (2)	60 W	8	0	480	0	960	0
M. Charger (1)	3 W	3	3	9	9	9	9
TV (1)	20 W	5	5	100	120	100	100
Total energy consummation (kWh/day)						1.159	0.199

Table 3-8: Load Consumption of BHS

Appliance	Rated Capacity	Operation (h)		Total energy		Energy consumption	
		Summer	Winter	Summer	Winter	Summer	winter
CFL (2)	6 W	5	5	30	30	60	60
Ceiling fan (2)	60 W	6	0	420	0	360	0
M. Charger (1)	3 W	3	3	9	9	9	9
TV (1)	20 W	5	5	100	120	100	100
Total energy consummation (kWh/day)						.529	0.169

In the proposed MG there are three different types system attached; large size SHS, regular size SHS, and BHS load consumption both winter and summer represents in the table (3-6), (3-7), and (3-8) respectively.

3.4.4 Battery storage system Design

In SHS and stand-alone PV system, most important component is battery. The BSS is indispensable in such system because of intermittent nature of solar PV. During the sun hour load directly connected to the PV array. Due to partial shading and cloudy hour, solar isolation is not sufficient for electricity generation. In SHS, battery configuration and design to operate with reliable and stable manoeuvre in evening peak load period.

3.4.4.1 Ampere – hour (Ah)

The measurement of battery capacity defined as Ampere Hour (Ah). In other words, it is an indication of how much energy can be stored by the battery and integrating discharging current in amperes over specific time. Ah, equal to transfer of one-ampere over one-hour. In the model, all batteries have 60 Ah capacity, which means delivers 3 A for 20 hours.

3.4.4.2 Capacity of the Battery

The measurement of a battery to store or deliver electrical energy, expressed as Ah. The capacity of the battery influenced its operational factors such as discharge rate, DOD, cut off voltage, temperature, and age and cycle history of the battery. The 12 V system of 60 Ah energy storage capacity designed as bellow

$$\frac{(\text{Nominal voltage of Battery} \times \text{Capacity of battery storage})}{1000} = \text{capacity (kWh)} \quad 3-20$$

$$\text{The capacity of Battery} = \frac{12 \text{ V} \times 60 \text{ Ah}}{1000} = 0.72 \text{ KWh}$$

3.4.4.3 Charge and Discharge of Lead Acid Battery

In the PV system, Battery plays an important role; during day time solar generating electricity battery stores energy and discharge during loads requires. During charging voltage applied to the battery which is set by the charge controller which is greater than battery voltage, and PV generated current drifts to the battery in reverse direction. During discharging state current drifts off from the battery to the loads as charge reduces instantaneously battery voltage drops quickly.

Depth of Discharge (DOD)

The percentage of battery capacity (Ah) extracted from a battery compared to the total charge capacity defined as DOD (in %). There are two important facts for the DOD in the PV based system.

Allowable DOD

The maximum percentage of full capacity withdrawn from the battery by the load called allowable depth of discharge. Low Voltage Disconnect (LVD) sets a point for the battery charge controller to allow an allowable DOD limit at a given discharge rate in a standalone PV system. In standalone SHS and other PV systems with Lead acid battery, considerable DOD is high as 80 % for the deep cycle [128]. In practice, allowable depth of discharge associated with the autonomy, the capacity of battery required to operate the system without energy from the PV array.

Average Daily DOD

Average daily DOD is defined as the percentage of full rated capacity of battery that is withdrawn from the load⁴ connected to the battery. The Average daily DOD varies through the load profile seasonally. Winter night hours in Bangladesh are longer than summer and other seasons, the average DOD will be higher in winter days than the rest of the day, due to lower capacity and temperature.

⁴ The load that is connected with the battery in the PV system is considered as the average daily load profile for the system.

State of Charge

The amount of stored energy remaining in the battery defined as State of charge (SOC). The SOC denoted battery fully charged, half charged, and completely discharged. The SOC of 100 % defined as battery fully charged, and 75 % of SOC indicated three-fourth (3/4) stored capacity remained for available further requirement. PV connected battery, charge increase in the battery but the charging current from the PV module decrease. A lead acid battery in low state of charge (SOC %) is close to 11 V and higher state of charge above 14 V.

Table 3-9: SOC level of 12 V SLI type Battery [129]

State of Charge SOC (%)	Voltage Level	Voltage level per cell
100	12.70	2.12
90	12.50	2.08
80	12.42	2.07
70	12.32	2.05
60	12.20	2.03
50	12.06	2.01
40	11.90	1.98
30	11.75	1.96
20	11.58	1.93
10	11.31	1.89
0.0	10.5	1.75

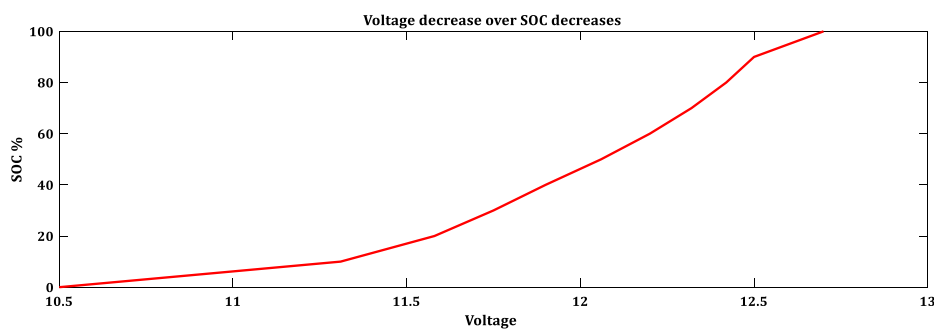


Figure 3-15: Lead-acid battery Voltage decreases over SOC decrease

3.4.4.4 Assumption of SOC for Lead Acid Battery

Internal resistance of battery keeps constant, during charging and discharging cycle does not vary with current.

- The parameters of battery deduced from discharge characteristics and keep same for charging characteristics same.
- Battery capacity (Ah) does not change with the value of current.
- The temperature, memory, and self-discharge does not take into account

3.4.4.5 Lead Acid Battery Modelling Charging & Discharging

Electric current supplied to the battery as charge current and stored. Charging process requires amount of time and depends on rate of charge current from PV source. In general low rate of current (3 % to 5 % of battery capacity) are the best for charging. Battery should not charging at rate current 10 % of battery capacity [130]. As example 100 Ah battery should not charge current more than 10 A. The 12 V DC system, solar charge power from 45 W_P and 65 W_P PV module generate no more than 4.5 to 5 A, which is well-matched for charging battery range from 60 Ah to 100 Ah Battery. The state of Discharge, when a load consumes the energy from the battery. The discharge current defined as the rate of current drawn from the battery during load consumption. Charging the battery by the PV system each day and then discharged through the load in each night. A 100 Ah battery charged up to 95 % of SOC within a cycle at 12.70 V. In the off-grid system typically number of days, need to last because each day is more or less the same as one cycle. In figure (3-16) represents discharging characteristics of Lead acid battery at nominal current.

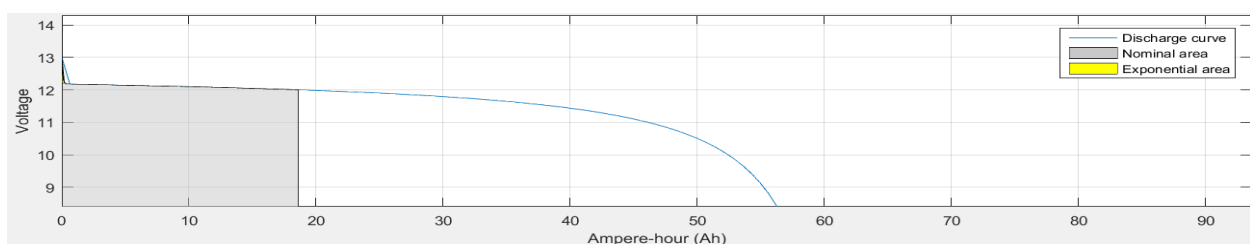


Figure 3-16: Discharge characteristics at nominal current

3.5 Charge Controller

In the PV system charge controller, prevent the battery from overcharging. During charging the lead acid battery charging current turn on, and battery voltage raise repeatedly. The internal resistance of the battery resists the charging current I_q , and battery voltage immediately rises above the open circuit voltage. Voltage gradually raises after the initial jump, and battery charged. Charge controller such as series or shunt connected charge controller interrupting as on/off, acts as a switch. Charging stage: controller allow all current flow to the battery from PV panel. The voltage rises to an upper threshold level distinct as “voltage regulation” set point the charge current turn off. Voltage drifted down with the time until research “Voltage regulation reconnection” the set point little down to VR, and again the charge current I_q (highlighted in green figure-3-17) turned back on. Continuously the battery cycle between VR and VRR set point. Presenting in figure (3-17) when the set-point voltage of VRR is lower, then PV array current interrupting for charging the battery. Other hands, if VRR is closer to VR set point, then controller element oscillate and making noise even harming the switching element.

In standalone PV system, charge controller regulates desire voltage and current for the system as required which is from PV panel drawn into a rechargeable battery. The DC output voltage of PV array supplies to the load through charge controller convert into the similar system DC voltage level.

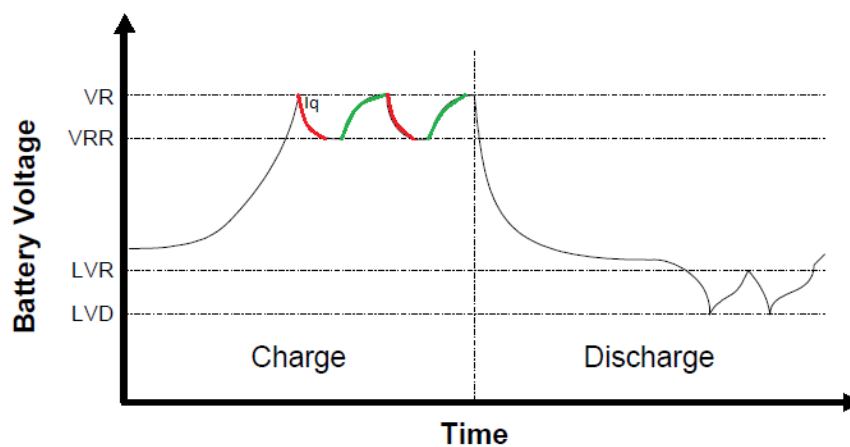


Figure 3-17: Charging and discharge state dedicate system On/off by charge controller

According to [129] there are two major operating conditions bellow:

1. Normal operation: When battery voltage fluctuates in between maximum and minimum set point
2. Overcharge and over-discharge: voltage researches some critical value

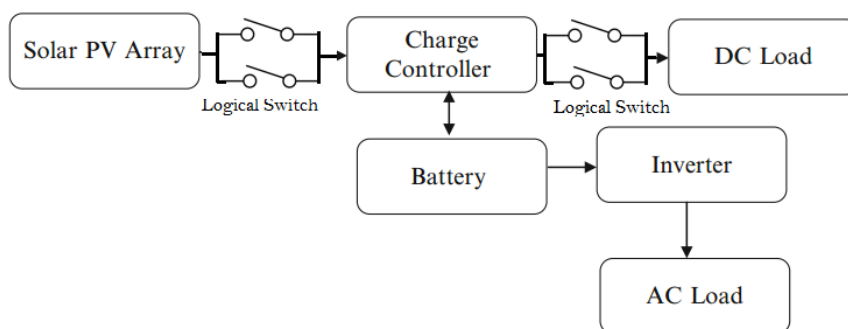


Figure 3-18: Block Diagram of Standalone PV system

Charge controller in SHS act as a switch, during charging process controller, allow current drift into the battery from PV. Battery connected with the PV panel for charging required and disconnected from the PV panel as fully charged without any damage. With the advancement of modern power, electronics PV charge controller, getting the utmost reliability in the system, efficiency of operation, and availability in action. The system configured along with PV panel, DC Load connected to the battery backup and other additional mechanisms for stabilizing the system. PV Array connected with battery and load to attain such as 12 V, 24 or 48 V [130]. By the means of dual DC cutoff disconnect charge controller output should have connected to the Battery. Apart from DC cutoff disconnect, manually operated switch employed in the system to disconnect the load and PV simultaneously. During charging the battery, regulate the output current to inhibit the voltage level from the exceeding the voltage level.

During the peak sun hour, PV power delivered to DC load connected to the PV panel in series and battery charging simultaneously. In standalone PV system, customize with MPPT scheme with a charge controller that offer maximum output driven power to the load shown in figure (3-18).

3.5.1 Charge controller design for Isolated SHS

The series charge controller scheme applies a constant voltage (V) to the battery and the set point of full charge VR (voltage regulation) by series connected control element present in (figure 3-18). It acts as a variable resistor. In the series controlled charge controller, either solid-state switch or relay switch instigated to open (off) circuit between the battery and PV module for discontinuing charging, or technically limit the current in the series linear manner to hold the high battery voltage.

Once again, controller reconnects the battery with PV panel when battery at bellow voltage from set point voltage of the system. The suggested design limits the current and holding high value of battery voltage. Current sensing the resistor in the controlled circuit so-called heat sinks circuit.

Series connected on/off (interrupting) controller containing with one-step control represent in figure (3-19), battery charging through the array either on or off. The controller monitoring the battery voltage during charring process constantly. When the battery voltage drops the PV module, reconnect to the value of set point voltage, the battery, and PV module reconnected, and the cycle repeats. When the battery full charged the battery voltage reach to the VR and the cycle execution time more and shorter.

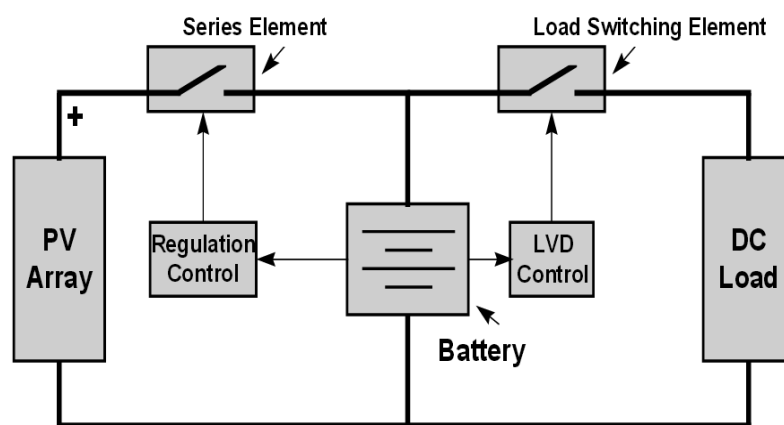


Figure 3-19: Block Diagram of Series controlled charge controller

Off controllers often, have difficulty fully charging batteries when the battery bank is small compared with the size of the photovoltaic array, a situation that tends to arise in systems with low levels of autonomy. This results from the relatively high charge currents

that occur during sunny days. The internal resistance of the battery causes higher currents to result in higher battery voltages. Thus, the gassing region and the VR set points reached a lower state-of-charge. Raising the VR set point does little to ameliorate this situation since it will simply permit more gassing. When the photovoltaic array will be regularly charging the batteries at a rate exceeding the C/20 rate, this may be a serious problem. If adding battery capacity ruled out, then constant voltage charging considered.

3.5.2 Battery Charge and Overcharge Protection

The PV module connected to the loads through charge controller shown in figure (3-19) and (3-20), the charge controller in the PV system which offers the system to protect over-charge and over discharge. The commonly used charge controller strategy based in On/Off interrupting [131]. Although this control strategy is not suitable for MG operation and applications while causes problem in battery charging process. Furthermore, in off-grid mode, no energy transferred into the battery, as energy not stored properly in the battery, and voltage regulation cannot possible in this scheme [132] In this scheme, the operating conditions and charge controller design as battery charging in constant voltage while DC MG system regulated in an acceptable range as considered [130]. The scheme also offers, charging and discharging the control the battery with the intention of smooth control the DC system, the battery power charge, and discharge in accordance with consumption load. Nevertheless, the charge controller designed by limit the battery discharge current and avoid over-discharging.

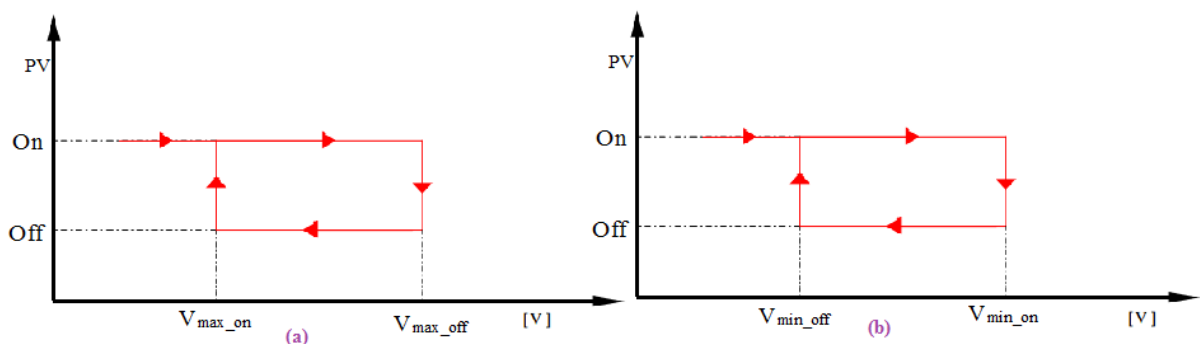


Figure 3-20: Operating Principle of protector (a) Overcharging and (b) discharging

According to the author of [130], the strategy of protection conditions represents in (figure 3-20a), the battery disconnects from the PV panel while the terminal voltage increases about certain threshold voltage (V_{\max_off}) and when loads require current which is lower than the current delivered by the PV module. The PV module connected to the battery when the terminal voltage decreases below a certain value (V_{\max_on}).

The battery system protects from the excessive discharge, the load needs to disconnect from the battery; when terminal voltage decrease at a certain threshold voltage (V_{\min_off}) and the load requires current which is bigger than current that current delivered by the PV panel. Load again need to reconnect to the system, when the terminal voltage above reference voltage (V_{\min_on}), and the switching cycle represent in the (figure 3-20b). The charge controller strategy operates under the conditions concise in the table (3-10).

Table 3-10: Summarize Charge Controller process and Conditions

	Conditions	Constrains of charge controller
(1)	PV panel disconnect from the system	$(I_{load} < I_{PV})$ and $(V_{terminal} > V_{\max_off})$
(2)	Reconnect PV panel in the system	Followed by (1) done $(V < V_{\max_on})$
(3)	Load Disconnect from the battery/system	$(V < V_{\min_off}$ and $I_{load} > I_{PV})$
(4)	Reconnect the load within the system	Followed by (3) done $(V > V_{\min_on})$

3.5.3 Battery charging without Charge controller

This section standalone SHS designed without charge controller, charge controller in general used to manage the energy flow from PV to Battery and load by sensing current and voltage with understanding the maximum and minimum set voltage for the battery. Without charge controller, two schemes valid together with “self-regulating nodule” and “battery size” has to considered, where CR (charger regulation) not required.

3.5.3.1 Low-voltage “self-regulation” PV module

In this section, medium size SHS and BHS designed along with low voltage PV module, battery, and DC load. Medium size SHS consisting of small size PV, battery, and load but BHS consisting of battery and Load. Both Medium and BHS scheme designed without

charge controller by self-regulation. The self-regulating 12 V DC voltage PV module considering with 36 multicrystal (Kyocera KC65T) cell in series, consequential an open-circuit voltage $V_{OC} = 21.7$ V and maximum power voltage about $V_{MPP} = 17.4$ V at STC 25°C. In self-regulation scheme proposition with no overcharge to occur, for this two factors considering for designing and settings for the system describes bellow;

The loads used consumes PV produced electricity on the daily basis. Battery obtains an excessive charge from PV, even though the module operates beyond knee charging current which is lower than maximum power current IMP. The loads consume daily, then the capacity of battery Ah receiving current from the PV module. This stored energy safely consumers by the loads daily without overcharging the battery.

Climate should not either cold nor warm. The average temperature of the location considered for this thesis in between 20 to 28°C present in (Appendix-4). If the climate is very cold, the knee of VI curves not move down inadequate voltage, as the current not generated from PV module. The self-regulated system also used in arctic climate region where the system used for lighting. The drop-off current extreme in the warm climate and crop off current very low in the cold climate [133]. Voltage 2.3 mV decreases at escalation of 1°C temperature [134].

3.5.4 Charge controller Design and Modelling for large SHS

Tow stage control PV array current immediately increase with battery voltage, when the load pulls down. Other control stages the current keep at small trickle charge level until the battery voltage gone down at range between 12.5 V to 12.8 V [135], before that point, the PV array current to resume. In large SHS with 45 to 165 WP, PV module produces a large amount of power and loads are connected to the battery instead of PV panel directly as shown in figure (3-20). Design and modelling of charge controller with PWM described briefly and its technical configuration and simulation. The solid-state switch has considered at very high frequency (20-30 kHz) for the applied pulse of current.

In the 12 V battery system, the voltage differs in between 10.5 V and 14.4 V, the depending factors are SOC, charge current and discharge current, type and battery age. When a full

loaded battery with no charging, discharging current flowing to the loads then battery voltage reach about 12.4 to 12.7 V.

During solar power generation, charging current is flowing to the battery the battery voltage jump to about 13.7 V (depending on charging current), now if the loads are connected by the switch (LVD = on) the voltage drop down to 12.0 to 11.8 V (depending on the system). If control (PWM) allows, then current flowing into the battery so voltage level increases up to 14.4 V. By means of overcharge protection, at 14.4 V charge controller switched off by PWM. At this stage the loads allow to connect with the system (LVD= on) and loads can consume energy, battery discharging, until bellow 11.5 V. If battery voltage below 11.5 V (control = off) by PWM for minimum period of time 30 s, and all loads also disconnected from the system by (LVD= off). Until battery voltage raised to 12.5 V, the loads are reconnected again (LVD=on). In PWM charge controller, Power dissipation is smaller than other charge controllers like series and shunt charge controller presents in figure (3-21).

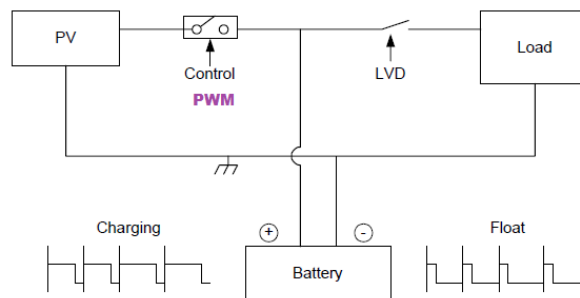


Figure 3-21: PWM controlled Charge Controller

3.5.5 Charge controller set point with different voltage level

Controller set points are the battery different voltage level. According to [133], there are four major set points has considered for controlling charging and discharging. VR and AVR voltage level refer for the set point for charging features that allow PV module is connected and disconnected from the battery. Similarly, load reconnects voltage (LRV) and low voltage load disconnect (LVD) set points state for charging the battery and allows. The charge controller set point in different voltage level present in (figure 3-22).

3.5.5.1 High Voltage Disconnect (HVD)

The region between VR and ARV dedicated in the presentation shown in (figure 3-22), where set point voltage has no limited to operate between this point. But the charge controller set as maximum in VR to protect overcharge of the battery. Once charge controller sense that battery reaches the voltage regulation set point, the controller either disconnect form the system or regulate the amount of charge current deliver to the battery shown in figure (3-22). In figure (3-22) present battery charging with a constant voltage, the amount of charge current which controlled by the regulator that battery hold at the set point for voltage regulation. In the practice, the battery in PV system allows charging whatever the current produced by the PV panel. In figure (3-23) represents battery charging with constant voltage charge controller VR set point considers little more than VRR (voltage regulation reconnect); the VR set point little lower than the voltage produces by the battery has been charged up at 100 % of SOC.

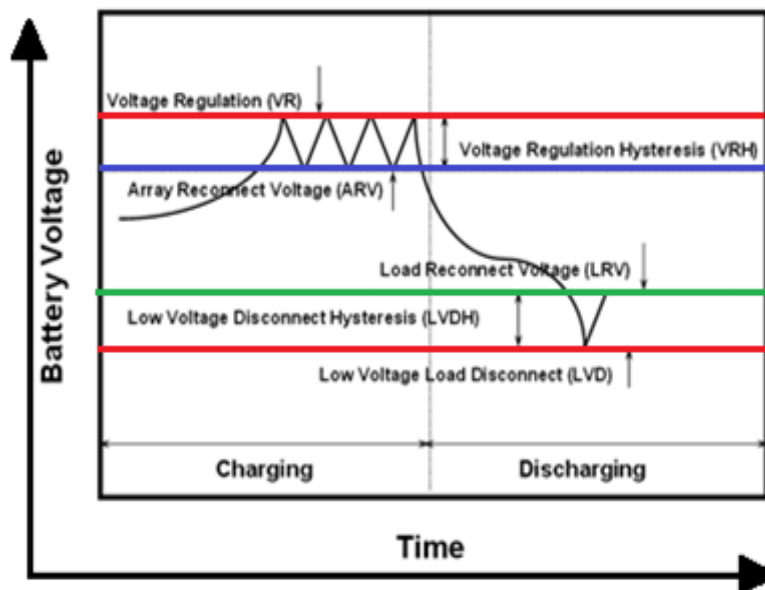


Figure 3-22: Charge controller Set point voltage

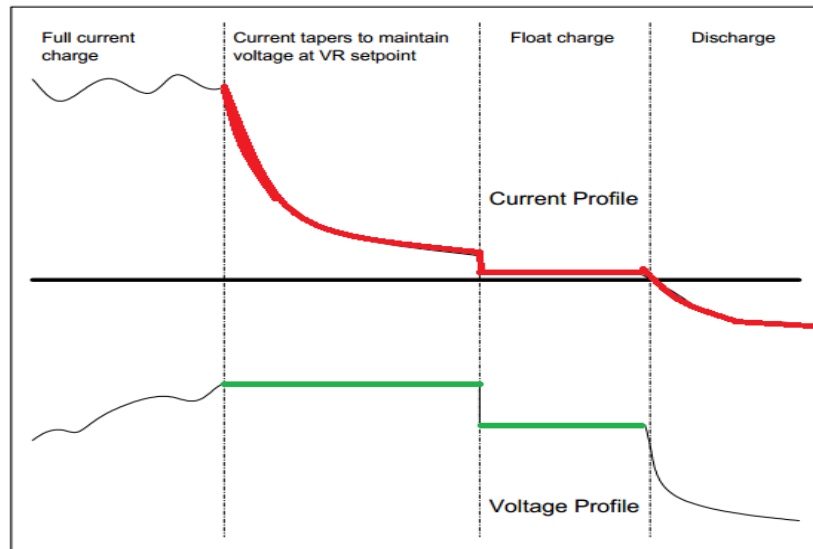


Figure 3-23: Battery charging with constant voltage

3.5.5.2 Voltage regulation: (VR) Set point Voltage

VR set point varying up or down depending on the battery type and operation strategy. Vindicating VR set point is difficult and stressful, but low VR set point approach avoids excessive overcharge. In practice, high VR set point allows ensuring full charge of battery cells. Photovoltaic charge controller with constant voltage charging process allow with whatever the PV current the PV module is able to deliver until VR set point shown in figure (3-23).

3.5.5.3 Array Reconnect Voltage set point

After disconnect due to overcharge charging point with respect to VR, battery voltage again decreases from VR set point. If charging and the discharging rate are high enough, the battery voltage is decreased at the higher rate. When battery voltage decreases at the predefined set point voltage of charge controller allows reconnecting the PV module. The voltage of the battery at where PV module again reconnect to the battery called (ARV) pointed in blue pointed shown in figure (3-22).

3.5.5.4 Low Voltage Disconnect Set point

Deep discharging of the battery has the negative impact of the battery performance including susceptible to freeze and shorten battery life. If the battery voltage drops down to the low level due to prolonged over load in the system or bad weather for the certain hour when PV does not generate PV current, charge controller disconnected from the load and avoid further over discharge. The set point voltage, where charge controller able to disconnected the load from battery delineate (LVD) red-lined shown in figure (3.22).

3.5.5.5 Low Voltage Reconnect set point

Disconnecting load from the battery at LVD set-point, battery voltage increases to open circuit voltage. When PV module connected to the system with battery, and battery charging up with the battery nominal voltage, a band of SOC high not enough (as proposal SOC=40 %) to reconnect the load again. The set point where charger allow the load to be reconnected called LVR. In practical practice, LVR should have 0.08 V/cell (0.5 V/ 12 V battery), and the voltage should be higher than LVD. An example if the charge controller LVD set-point defined at 12.5 V then the LVR at 13.0 V.

3.6 Technical Standard of charge controller of SHS in Bangladesh

The charge controller of PV system and SHS used in Bangladesh, the specification of low voltage disconnect (VLVD) and high voltage disconnect (VHVD) considered VHVD = $14.3 \pm 0.2V$ and VLVD = $11.6 \pm 0.1 V$ [136]. There are several types of lead acid battery typically used in SHS of Bangladesh, in the table (3-11). The Depth of Discharge (DOC) considers 70 % to 60 % that prolongs to the SOC of the battery coupled to the load. Solar replacement ratio (SRR) is the indicator which expresses, the percentage of demand that replaced by the solar during light, and the battery can be charged simultaneously present in equation (17). The battery charge cycle considered as 40 % to 100 %; on every occasion the SOC below 40 %, power from the MG (DC bus) deliveries to the load.

$$SRR = \frac{P_{\text{demand}} - P_{\text{DC}} - P_{\text{SOC}}}{P_{\text{demand}}} \quad 3-21$$

Where

- P_{Demand} = Power demand for the load connected in the system
- P_{DC} = Available power from the DC bus
- P_{SOC} = Battery power

Table 3-11: Recommended Charge controller regulation for Lead acid Battery [137]

Regulation Voltage 12 V	Battery types	
	Flooded (PbSb)	Flooded (PbCa)
LVR	14.4-14.8	14.0-14.4
LVD	12.0 ± 1	11.5 ± 1

3.7 Micro grid configuration and Design

Distributed renewable energy integrated MG seemed to be exploiting the alternative and future source of energy, reducing the environmental risk. Last few years due increasing the population, comfort, and life standard style, however, the dependency on machinery demand of electrical power increasing rapidly [138]. With achieving the vision 2020, energy access in the country like Bangladesh, where the main extension both economically and technically not feasible, but average 6 kWh/m²/day solar irradiation and 10 h solar energy generation and huge amount of biomass waste offer a sustainable and reliable energy system is the best solution in Bangladesh; the infrastructure and formation is main problem in such power system. The authors of [139] finding that a large AC grid not economically not sustainable in Bangladesh, while a large number of small size electrical appliances which can also operate by the small scale DC grid rather than 220 V AC system. The loads mainly considered which used in rural areas that also configured in DC such as CFL or LED light or incandescent lamp, DC ceiling fan, mobile charger, DC powered TV and DC brushless water pump for irrigation and rice mills.

The optimal design of MG generalized into two classifications such as an optimal design with suitable configuration and planning for operational strategy of MG [140]. According to IEG, to improve energy access in the developing countries should dispense to grid intensification rather than configuring the standalone system, whereas in Bangladesh, India, sub-Saharan-Africa solar PV based project have a lower cost per connection and comparatively easy to implement [141].

The proposed system design is focused on long-term, which involves PV configured SHS, and a community based biomass-fuelled CHP, electric power delivered to the household loads and community based cold storage load. In this section, MG configuration and optimal design proposition with decentralized DER components like PV and Biomass has chosen for the best suitable source of energy. The configuration of MG scheme shown in figure (3-24) in the proposed site in Bangladesh, where AC and DC sources and loads are connected corresponding AC and DC network respectively. DC networks configure with integrated SHS and main grid (AC network) coupled within DC MG through PCC (point of common coupling). The PCC associate together through a pole-mounted transformer described in next section (3.7.3). AC network system tied to the national grid and with CHP generation source.

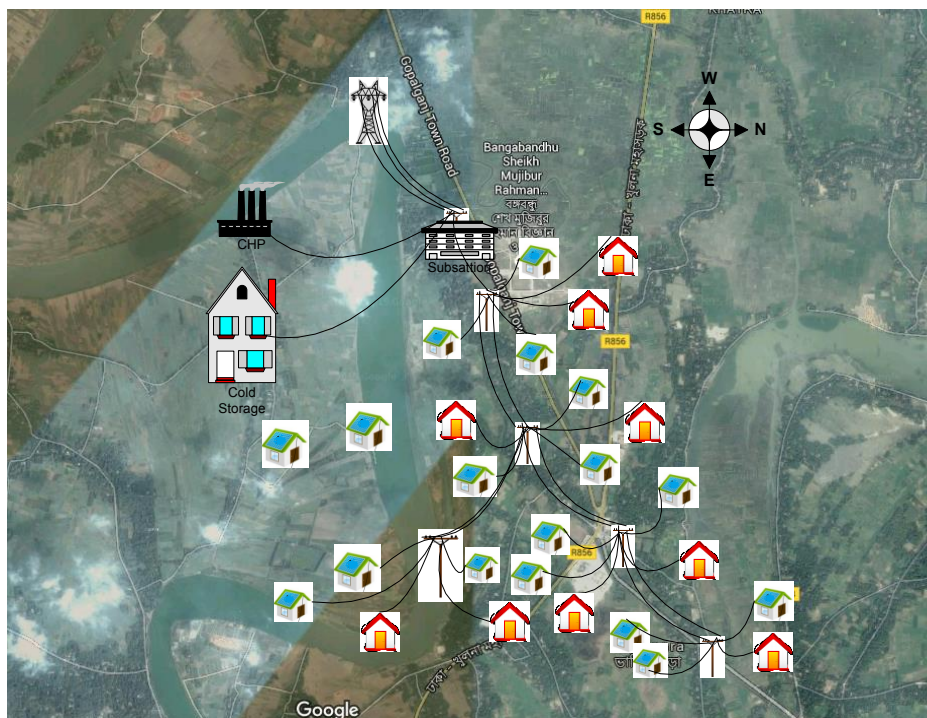


Figure 3-24: SHS and BHS integrated micro grid (MG) @ google earth

The proposed MG consisting of AC and DC network have their corresponding decentralized generation sources, and load and battery storage. AC network connected to the AC load (cold storage), circuit breaker. Grid power transfer through pole mounted transformer to the DC grid where SHS and BHS connected in the 12 V DC system. PV arrays are mounted within the SHS, and 60 Ah Lead acid battery mounted with the 12 V system. SHS system connected in parallel within the system. The variable DC loads connected within the SHS and BHS.

In the figure (3-24), the proposed MG system, which coupled with several SHS and BHS configured. The proposed MG proposition that allows operating in both standalone and grid-tied operation mode, where system configured with DERs that consist of PV system distinct as SHS and biomass-fuelled CHP distinctively produce electrical power and thermal energy consumed by cold storage. The CHP in the proposed scheme which consists of a small scale MT that produces electricity and thermal energy simultaneously. Remote area, pier-urban, and small village far away from the national grid suitable for this proposed system.

3.7.1 DC-MG Scheme

The conventional energy sources like fossil fuel, coal are exhausting and becoming expensive day by day; while spreads greenhouse gasses including CO₂ that causes global warming alarmingly. Considering these challenges, adopting local renewable energy sources that have the potential to transformation at the point of end users without conversion which also avoid inefficient energy transport [142]. Inspiring with the sustainable strategies to form several individual clusters within rural areas that configure with 100 % of local renewable sources to meet own energy demand. The DC system, there only active power include voltage and current involved in efficiency [143]-[144], whereas AC system consents TDH (total harmonic distortion) caused by the loads or effect of inductance of distribution line and loads causes reactive power flow [145].

The DC grid configures with DC power generated a source of energy, the proposed scheme PV is the well-suited source that well defined as SHS, which distributed within 0.5 km and a smart power management strategy looked forward to coordinating SHS

along within the system and battery storage system effectively. The batteries and load are connected within the SHS, the PV panel produces power delivered to load and battery, to protect the battery from excessive overcharge and discharge by a charge controller, and DC - DC bidirectional converter used in the system which coupled SHS within the DC bus shown in figure (3-24). Loads of both large and regular SHS considered in (section 3.3.3), the peak load configured with 1.14 kW and 0.7 kW respectively, however, solar power generation higher whereas the load is lesser than the demand A 60-80 Ah battery used in each SHS. In (figure 3-24) presents, the battery, associated loads, and PV panel coupled in the SHS through a DC-DC converter that controls the DC MG system.

The DC-MG show in figure (3-25), the advantage of this scheme in the relationship of the system efficiency enhancement by eliminates DC/AC or AC/DC conversion. The proposed DC system operate in both off grid and grid tied as AC [146], grid connected mode considered while PV predictable to operate in MPPT and delivered maximum power to the loads, batteries, and surplus electricity to the grid. The main grid in the proposed scheme, act as a supportive grid which has the ability to supplies power into the MG at the same time the surplus power produces by the DC grid (SHS associated in the DC grid) sells back to the main grid. Total power produced by the DC system present in the (equation 18)

$$P_{\text{Total}} = P_{\text{PV_DC}} + P_{\text{Battery}} - P_{\text{Load}} \quad 3-22$$

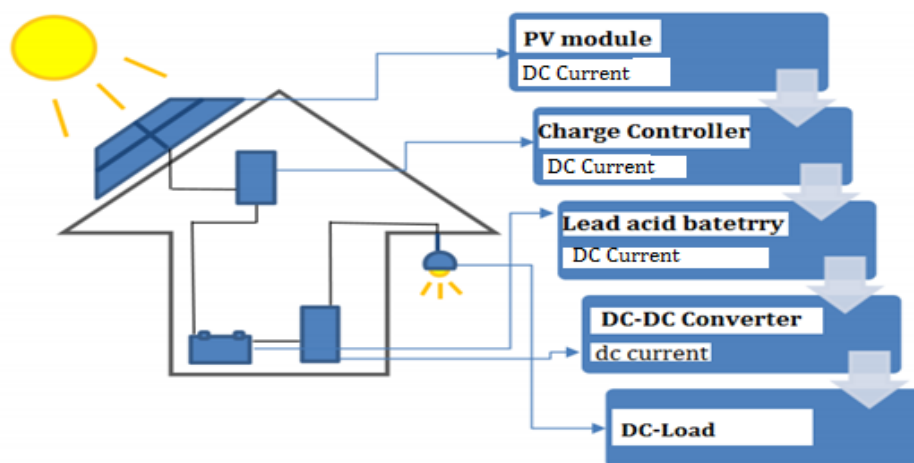


Figure 3-25: Layout of typical SHS configuration

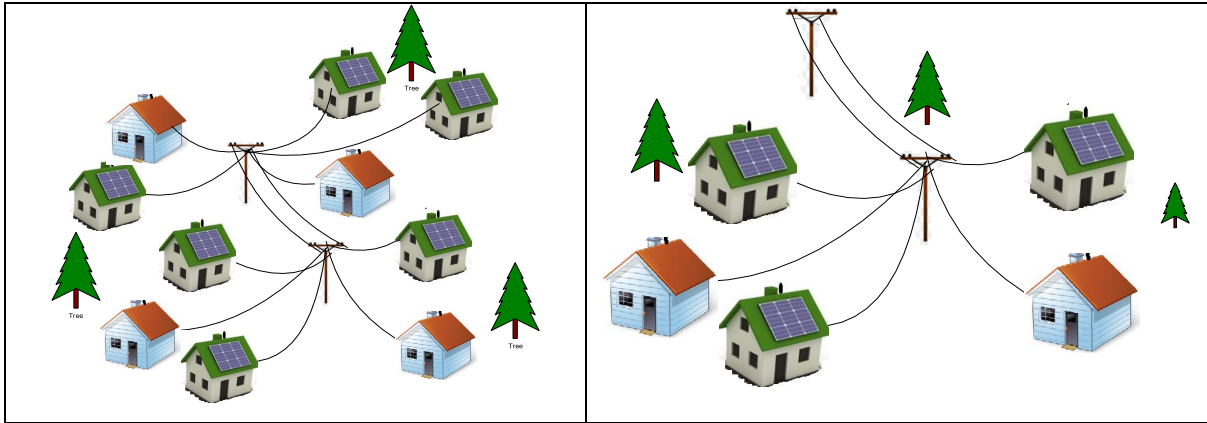


Figure 3-26: DC-MG: 2 small cluster (left) & single cluster (right)

The concept of the DC MG with a low voltage which configures along with large size SHS, regular size SHS, and BHS; the scheme suggest and developed by multi-MG arrangement. According to the authors [147], several small size MG clusters integrated within a big size cluster present in figure (3-25) and (3-26). According to the scheme the configuration small size cluster consists of one large size SHS, two small sizes SHS and 2 BHS and connected in common point shown in figure (3-26). The individual small cluster which has the capabilities that self-healing network and operates as one MG, and also enable to affluence variable network topologies represent in figure (3-27).

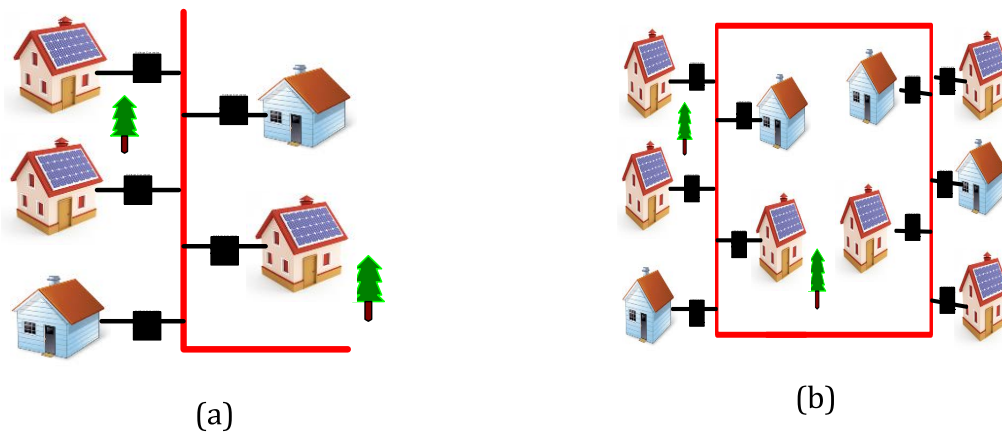


Figure 3-27: Layout of DC MG: (a) Radial network and (b) ring network

The traditional network for rural electrification arrangement either radial or ring. In the proposed scheme suggested as radial network shown in figure (3-27a), which ease to consumption and conceivability to generate simultaneously and connected in parallel in

the same network shown in figure (3-27a and 3-27b). Energy access to rural areas both radial or ring network deployed but the operation should be radial.

The author [148] defined the capacity of battery in SHS defined in (equation 19)

$$\text{Capacity} = \frac{E \times A}{V \times T \times \eta_{\text{cable}} \times \eta_{\text{converter}}} \quad 3-23$$

Where,

- E = Daily energy requirement for battery sizing (Wh)
- A = Days of autonomy, i.e. number of days of storage required
- V = System voltage (12 V)
- T = Maximum DOD of the battery (0.3–0.9) and co
- $\eta_{\text{converter}}$ = converter efficiency (0.8–0.95)
- η_{cable} Efficiency of the cables delivering the power from the battery

3.7.3 Pole Mounted Transformer

The DC MG connected to the main grid by a static device consisting of two winding without a magnetic core; power transfer by electromagnetic induction in between two circuits at the same frequency but different voltage and current. The proposed DC MG system configures along with 12 V SHS and DC bus 24-48 V whereas the main grid 230 V. Main grid side three phase 6.6 kV AC current coupled to the pole mounted transformer and in the MG side 220-230 V to the single phase. The main grid system frequency set at 50 Hz. The SHS and BHS are connected to the main grid by single phase 220-230 V AC line. The pole mounted transformer defined as the substation in figure (3-24) and MG model presents in MATLAB/SIMULINK environment attached in (Appendix-1)

Summary

Standalone PV system, especially SHS has been a significant growth across the rural areas in the country throughout last five years in Bangladesh. The research investigates and demonstrates, the PV technology adaptability and flexibility for designing in different

regions with the different scheme. In the remote areas, it is straightforward to design a stand-alone system which possible to adopt with bottom up swarm concept, where energy can be sharing among participants' in the system. Similarly, the country like Bangladesh where biomass potential has seen enormous prospective to produce electricity by small scale CHP or micro-generator. Almost 2.0 tons/day production of biomass resources available from agricultural based regions, where agricultural biomass waste and animal manure used a fuel and the process considers either gasification or combustion taken into consideration to produces 35 % of electrical power and 75 % of thermal energy from micro-CHP. Country like Bangladesh where summer season comprises with 10 months, while average solar irradiation 4.5 kW/m²/day offer sufficient electricity for both daytime and evening electric load demand, and the enormous biomass potential that generate electric power and the thermal energy can be converse into chill and usage in the cold storage to store huge amount of crops. PV produces DC current and modern technology offers DC generators and integration of these two potential to configures DC system, where the appliances also comply with the DC system. The optimal MG design scheme and sizing describe in chapter-5.

According to the proposed design, PV system (SHS) coupled to the DC bus, and m-CHP tied with AC system with the main grid and cold storage also connected into the AC system. Electric power and thermal power produces by congregating m-CHP unit which located on site or distributed through AC or DC bus, the electricity delivered to the loads through to AC grid if cold storage connected to AC bus. The cold storage can be connected to the DC bus in MG, a DC micro-turbine can be used to produces electric power and thermal power or directly to loads without the grid. The thermal energy converts into the chill air by thermal driven absorption chiller. The advantage of μ -CHP system has the ability to improve both electrical and thermal efficiency 33 % and 65 % respectively.

The studies show inclusive of decentralized electric power generates by several SHS and m-CHP, among all SHS coupled in parallel in the DC bus and followed by the radial network. Improving the efficiency both DC MG system and distribution, a dispatching model that comply by optimal size design, planning for desired operation strategy for the specific application. The efficiency also depends on the number of converter and charge controller used in each SHS, load power consumption, battery capacity and SOC.

Chapter 4

Microgrid and Components Modelling & Simulation

Introduction

The proposed MG consists of several components, where PV modules are one of the major elements in the system. In this chapter, MATLAB/SIMULINK based modelling and simulation result will be briefly discussed. The PV model mainly designed stand-alone mode, along with PV system battery and load also considered during the simulation and result also shown. The operation of MG conceded for the grid-connected mode. Along all the elements of MG also connected through the system. The PV module, cell temperature also taken under consideration for studying and analysis the MG, and SHS. The resulting analysis was done by using MATLAB/SIMULINK, and the result presented in graphical and verbal throughout this chapter. Individual PV panel as DERs source, DC loads, charge controller, DC-DC converter, battery charging and discharging and combined MG modelling and simulation tested and analysis their result simultaneously. PV panel using empirical mathematical equations and its characteristics such as temperature, solar insolation shown in figure (4-1) of the proposed location, and mathematical equation implemented and modelled the MATLAB/ SIMULINK based environment in section (4.1 PV Module Modelling and Simulation). The implementation of PV general equations and modelling in SIMULINK is precise and straightforward.

There are many charge controller schemes with unidirectional DC - DC converter, the two independent control strategy are obligatory for battery charging and discharging. In the proposed system battery charging and their sharing energy is important for reliability. The multiport converter may collectively use in the system shown in figure (4-39). The converter used in the renewable integrated system are characterized as non-isolated and isolated. As the proposed system does not require a transformer or another such devise for increases or decreases voltage and current level, and the non-isolated converter is preferred to implement. The system where no access to the national grid or remotely designed MG with battery storage system preferred to use unidirectional DC - DC Converter.

The simulation results will be measuring of each individual elements model deployed in the system by MATLAB/SIMULINK, the result will also be discussed in this chapter.

4.1 PV Module Modeling and Simulation

In contemporary practice, the performance of PV module has influenced by its known conditions. The electrical performance and efficiency of the PV module characterized by the manufacturer are some special conditions counting with Standard Test Condition (STC) and Nominal Operating Cell Temperature (NOCT). NOCT (reference) condition parameters delivered to the module together with ambient irradiance G_a , ambient temperature T_a , the temperature of the cell T_c . Under STC condition followed by solar Irradiance G (W/m^2) and cell temperature (K), at least following parameters are measured:

- Short circuit current for the module, I_{SC}
- Open circuit voltage for module, V_{OC}
- Maximum power for the module, P_{MAX}

Factual Solar data for Gopalganj, Bangladesh of the year 2013 is especially global horizontal surface insolation with solar orientation preferable at south and tilt angle 23.76 (NASA, 2015) to allow the maximum power production. At the optimum, tilt angle for a fixed type solar collector as acquires maximum possible radiation through the year present in figure (4-1).

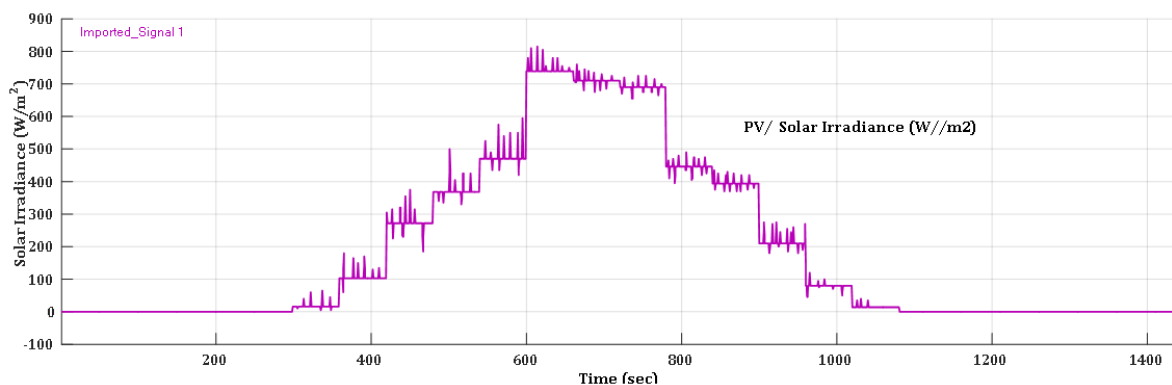


Figure 4-1: Solar Irradiance in the Proposed MG site @ 30 June, 2013

Modelling the PV system developed in Simulink; at first PV array developed based on mathematical equations. The individual mechanisms of PV module considered by mathematical equations and parameters. Figure (4-1) represent the PV module in Simulink model is responded by the different temperature. Figure (4-2) and (4-3)

portrayed the output characteristics including photovoltaic current, voltage, and power of proposed PV module.

Table 4-1: Kyocera PV Module Specifications

Electrical Performance under Standard Test Condition (STC)	
Maximum Power (P_{MAX})	65.0 W
Maximum Power Voltage (V_{MPP})	17.4 V
Maximum Power Current (I_{MPP})	3.75 A
Open Circuit Voltage (V_{OC})	21.7 V
Short Circuit Current (I_{SC})	3.99 A
Temperature coefficient of V_{OC}	$-8.21 \times 10^{-2} \text{ V}/^\circ\text{C}$
Temperature Coefficient of I_{SC}	$1.59 \times 10^{-2} \text{ A}/^\circ\text{C}$

STC: irradiance 1000 W/m², AM1.5 spectrum, Module temperature 25 °C

Electrical Performance Under Nominal Operating Cell temperature (NOCT)	
Maximum Power (P_{MAX})	46 W
Maximum Power Voltage (V_{MPP})	15.03 V
Maximum Power Current (I_{MPP})	3.01 A
Open Circuit Voltage (V_{OC})	19.70 V
Short Circuit Current (I_{SC})	3.22 A

NOCT: irradiance 800 W/m², AM1.5, Cell temperature T_c : 47 °C

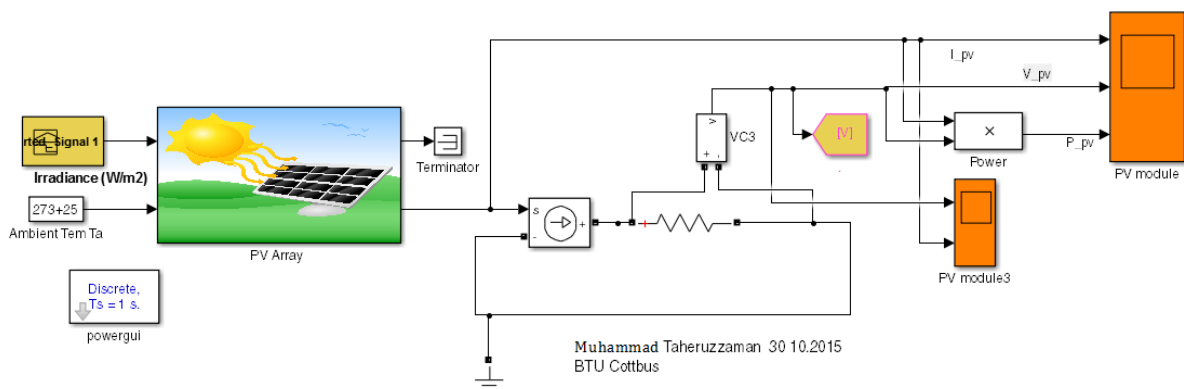


Figure 4-2: Proposed PV Module in Simulink Model

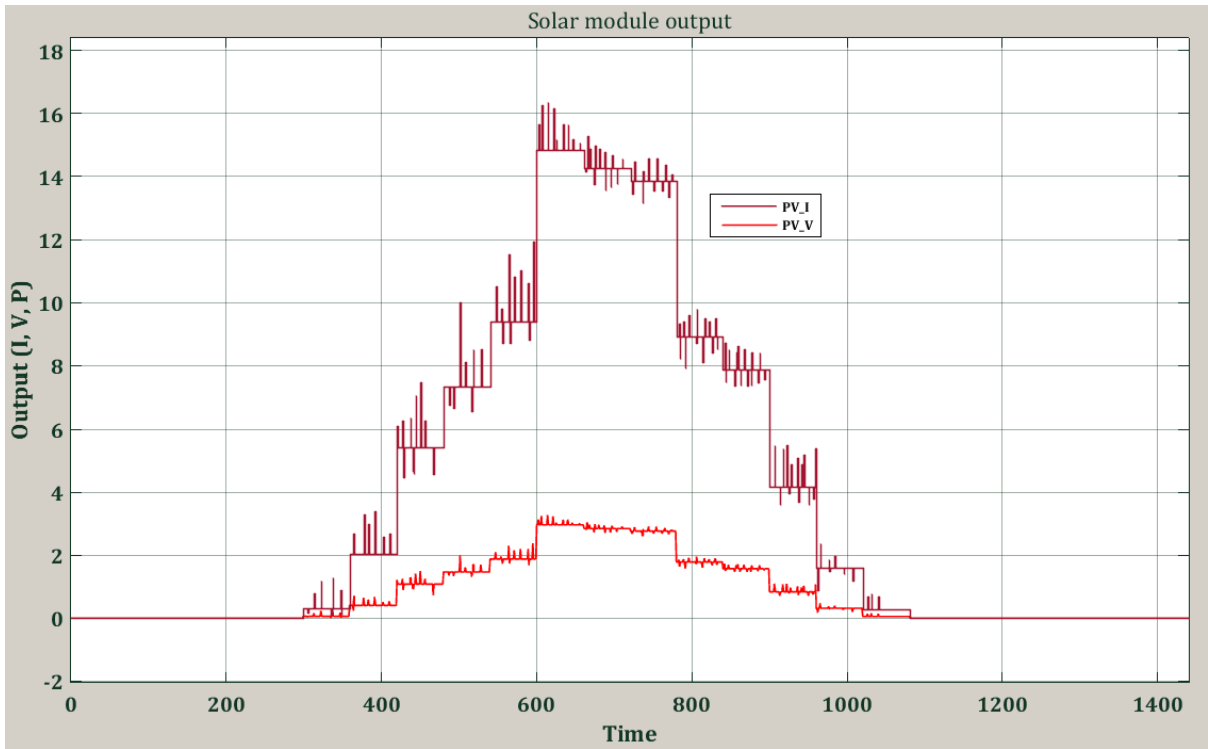


Figure 4-3: V-I Characteristics of proposed PV module

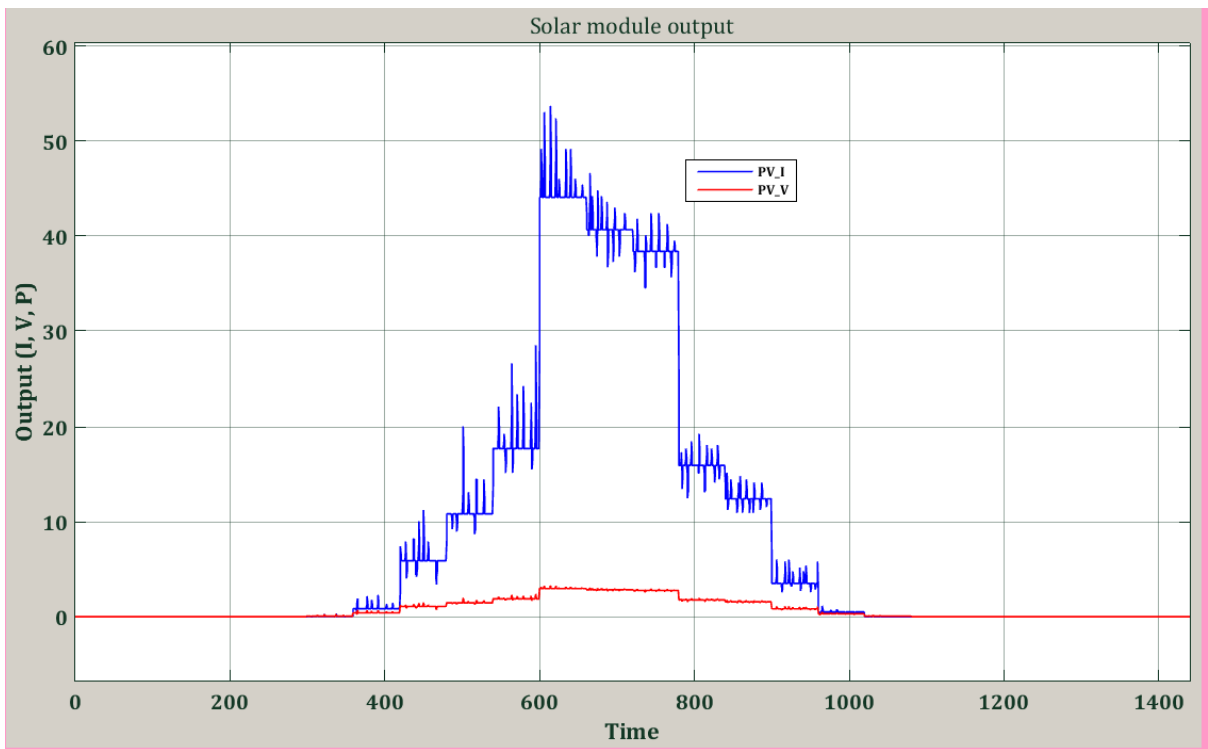


Figure 4-4: P-I Characteristics of proposed PV module

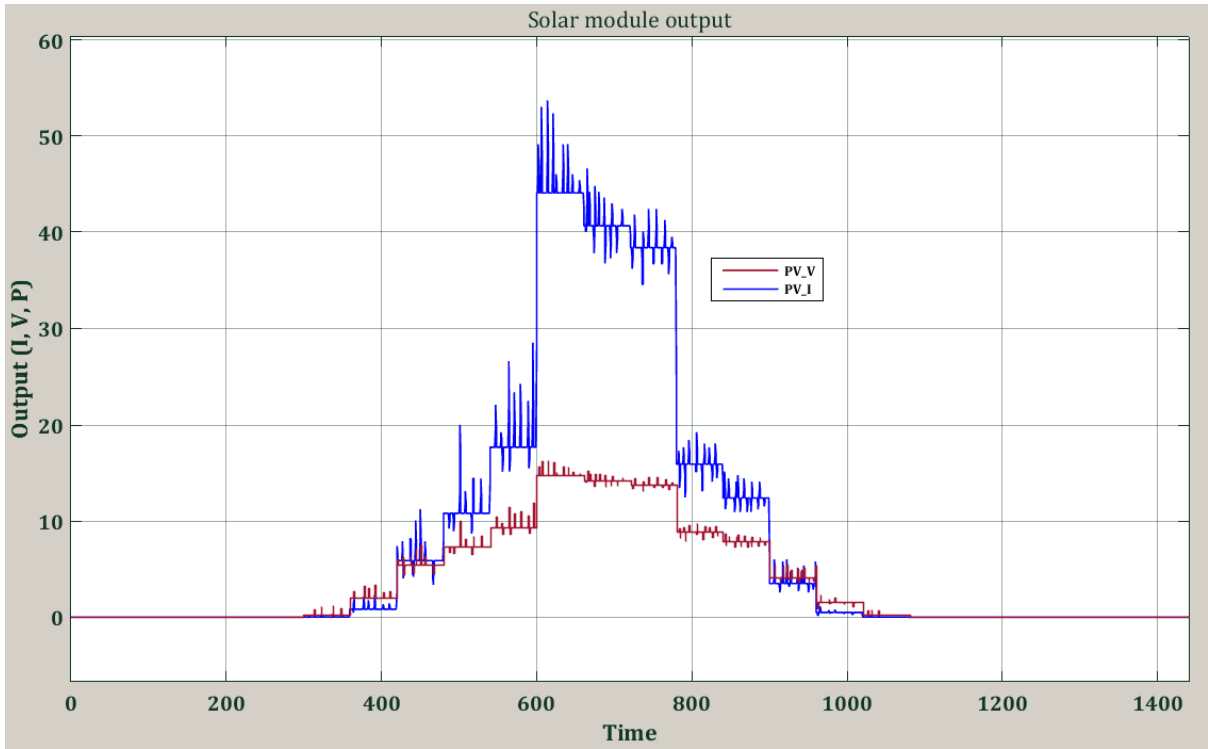


Figure 4-5: P-V output characteristics of PV module

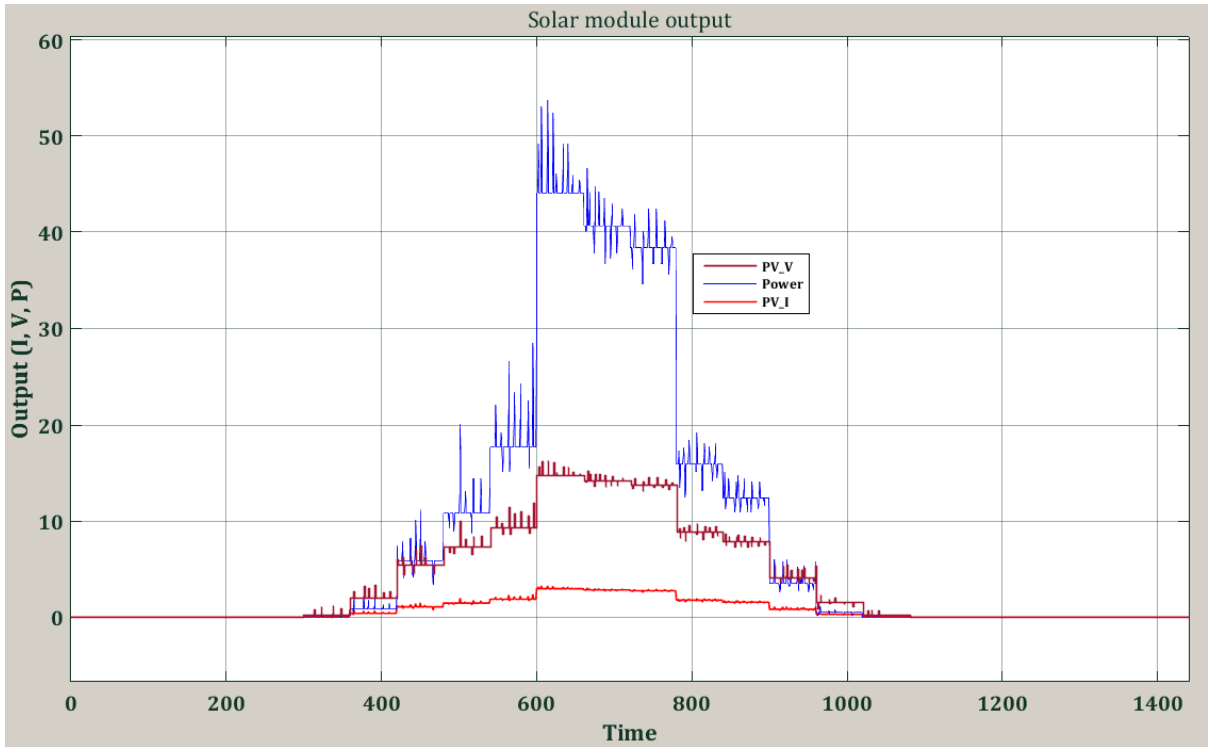


Figure 4-6: PV module output characteristics of PV module

4.1.1 Temperature Effect on PV

Among (4-3) (4-4) (4-5) (4-6) all those characteristics figure shown, the generating current varying with respect to ambient temperature and solar irradiations. Solar Module output affected by both solar irradiation and ambient temperature. The PV module generating current and voltage increasing, thus resulting power increased by solar irradiation.

As increasing ambient temperature (T_a) affected PV module terminal voltage, while PV generating current kept constant and resulting power slightly increased shown in figure (4-7) and (4-8) respectively. According to the representation of figure the peak output power 54 W at 30 °C and 55 W at 47°C shown in figure (4-7) and (4-8). The cell temperature depends on PV cell material which is described in temperature coefficient of open circuit voltage V_{OC} . Most of the PV panel including polycrystalline and Multicrystal module PV panel, temperature decreased by ambient temperature (T_a °C), the voltage increased by 0.12 V [149]. The empirical equations of PV open circuit voltage and cell efficiency present (4-1) and (4-2) bellow;

$$V_{OC} = K_V \times T_{STC} - T_a + V_{OC, ref} \quad 4-1$$

$$\eta_C = \eta_{T,ref} [1 - K_V (T_C - T_{ref})] \quad 4-2$$

Where,

- V_{OC} = Open circuit Voltage (V)
- η_C = Cell efficiency
- $\eta_{T,ref}$ = Module electrical efficiency at reference temperature
- K_V = Temperature Coefficient of open circuit voltage (V/°C)
- T_C = Cell temperature
- T_a = Ambient temperature
- T_{ref} = Reference temperature (25 °C)

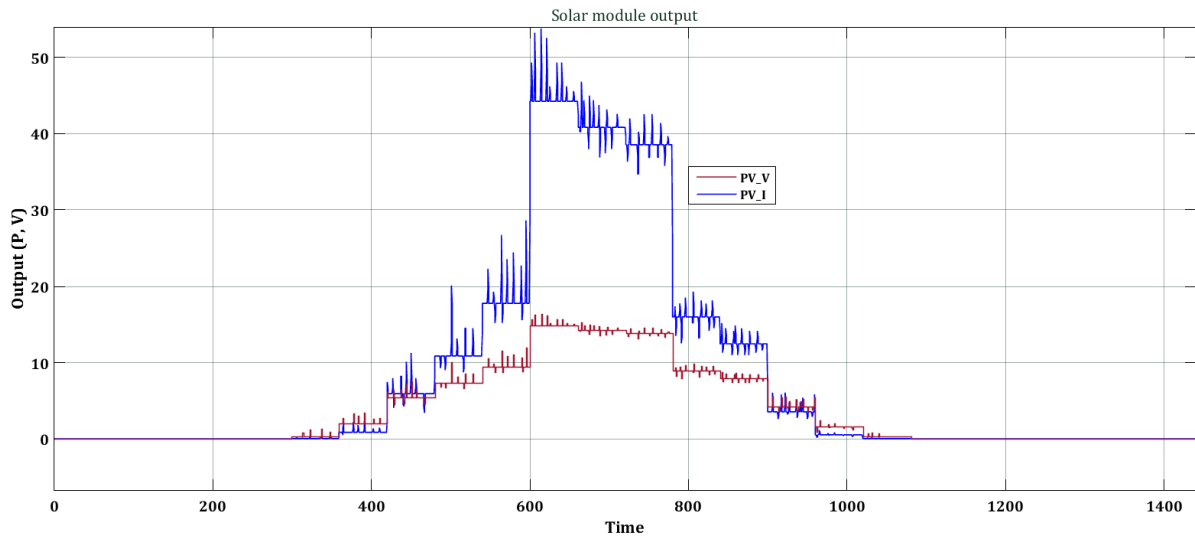


Figure 4-7: P-V Output Characteristics @ 30 °C

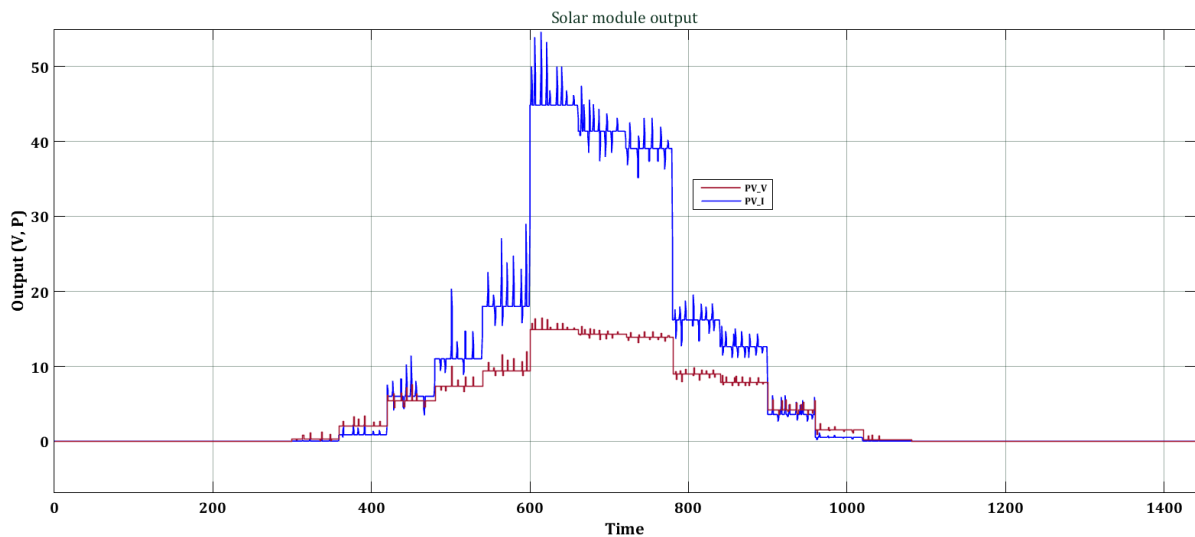
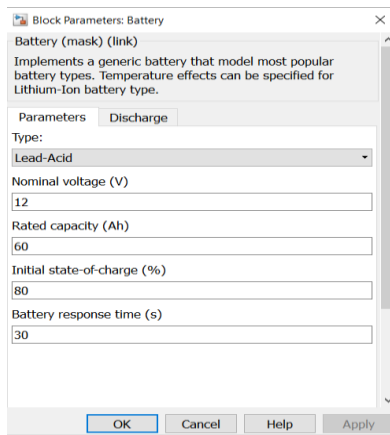


Figure 4-8: P-V Output Characteristics @ 47°C

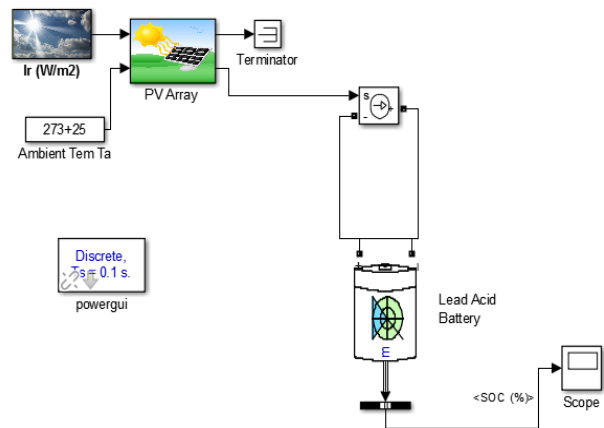
4.2 Battery Charging and discharging simulation

4.2.1 Lead Acid Battery Charging Model

The individual Battery of the proposed MG considered as energy storage, lead acid a 12 V, and 60 Ah connected to all SHS and BHS. The loads of SHS and BHS connected in parallel. When state of charge (SOC) is lower than 40 %, then load disconnected from the battery through charge controller.



(a)



(b)

Figure 4-9: (a) Parameters of Lead acid battery & (b) Battery model charging with PV

Lead acid battery from MATLAB/SIMULINK Sim Power System generic dynamic block taken, the parameters of Lead acid shown in figure (4-9a) considered according to MATHWORKS library [150] and battery charging with different solar irradiation shown in figure (4-9b). The nominal voltage of lead acid battery represents the end of linear of battery discharge, after reach that level voltage decreased shortly. Rated capacity (Ah) minimum effective capacity of battery under consideration, the capacity of battery; amount of energy released from a fully charged battery during discharge with a current, voltage and temperature. For an example, the current require for charging $I = C/20$; capacity $C = C_{10} = 60 \text{ Ah}$, the current of battery $I = 60 \text{ Ah}/20 = 3 \text{ A}$. Initially state of charge 100 % distinct battery fully charged and 0 % denoted battery is empty.

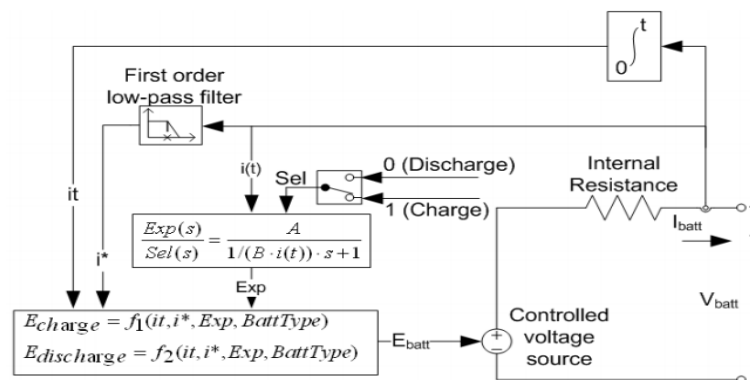


Figure 4-10: Equivalent circuit diagram of Lead acid the battery block

As the battery is being charged at constant current, the voltage remains near its nominal value (1.2 V in the example) and rises abruptly to a peak when the battery is almost fully

charged. This voltage rising, remarked in the figure (4-13) with circled, starts when the cell enters the overcharge danger zone. From that instant, the temperature begins to rise rapidly since the chemical changes are complete and the excess of electrical energy is converted into heat. This point can therefore be detected by the increase of voltage and used to identify the peak charge and to cut off the charger when the battery has reached its full charge.

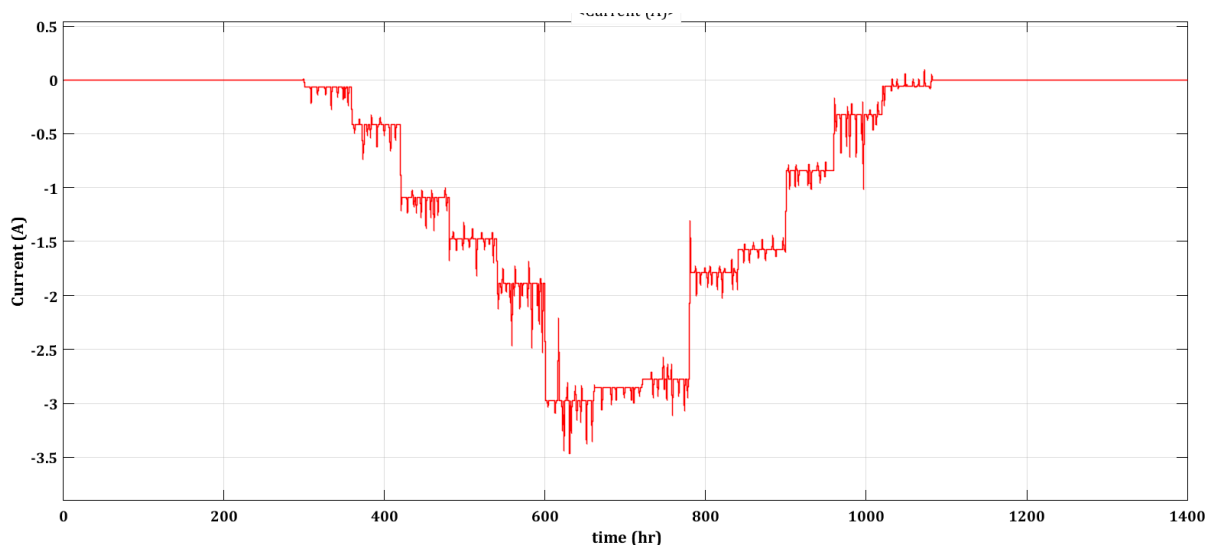


Figure 4-11: Lead Acid Battery charging with variable PV Current

During charging with variable current (generated during solar irradiation), at the beginning the voltage remains as nominal battery voltage (12 V) but voltage increases abruptly respect continuous charging over period of time. Voltage raising observed in figure (4-13) with blue circle peak charging voltage about 14.3 V, and black circle represent the fast charging voltage about 14.4 V of Battery. The battery voltage increases slowly with respect to PV current generated over solar irradiation. The battery continuously absorbing charge and charging rate gradually slow down. When battery about to full charged, the charging current gradually decreased. The simulation result of SOC of battery that increases during the solar peak hour in between 10:00 h to 14:00 h, and the initial SOC increases from 60 % to 75 % show in figure (4-12).

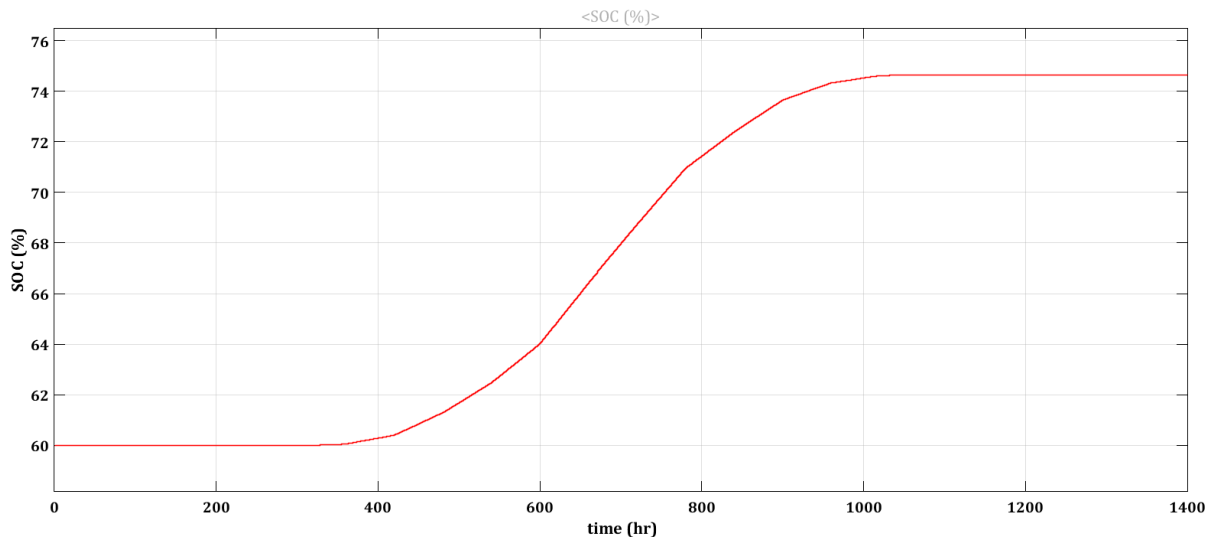


Figure 4-12: Simulation result of SOC over time for a day

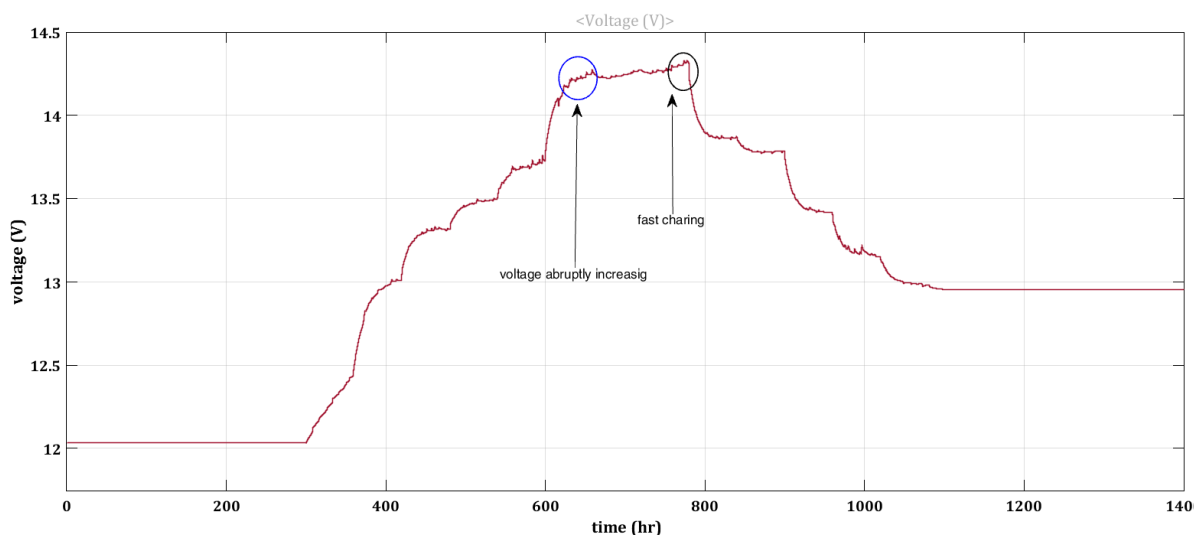


Figure 4-13: Battery Voltage

4.2.2 Discharging with restive load

A typical DC Load (resistive) are connected in parallel to the battery. Considering a constant restive load with the system. As the PV system produce 45 to 55 W_P between 10:00 - 15:00 h, at that time battery, can charge and discharge simultaneously. In figure (4-15), (4-16) and (4-17) represent the discharging current, discharge voltage and SOC simulation result in Simulink environment. In figure (4-14) present the layout of solar

Home system without charge controller which represent battery charging by the battery connected in the system and discharging through the resistive load.

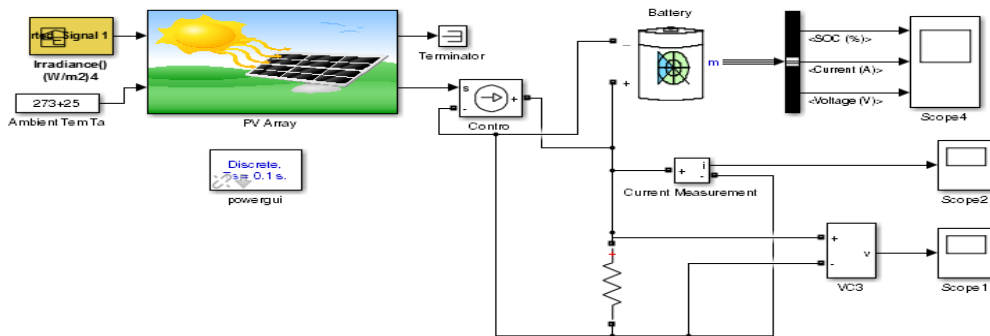


Figure 4-14: Battery charging and discharging simulation

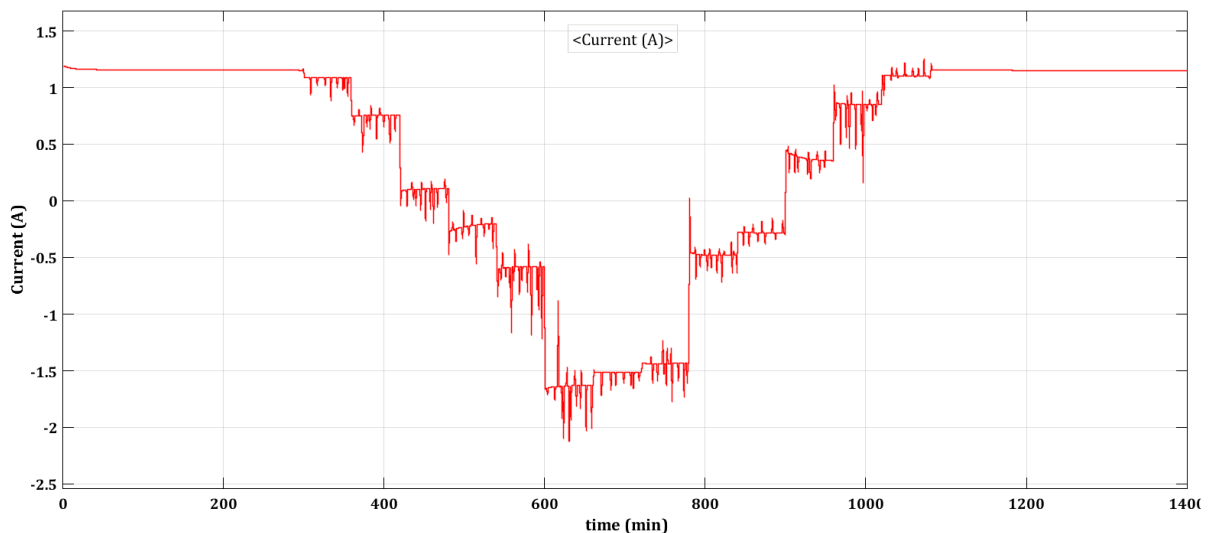


Figure 4-15: Discharging Current of Battery Simulation

As shown in figure, (4-15) discharging current of the battery over a day, and in figure (4-16) until 8:00 h the battery discharged, in between 8:00 h to 10:00h due to low solar irradiation the SOC level almost constant, soon after the solar irradiation starts the Module start to produce PV current shown in figure (4-15) and the battery starts charging till 15:30 h, SOC level shown in figure (4-16). The solar generation is not enough to charge the battery and battery starts discharging shown in figure (4-16), the battery charging and discharging without charge controller discharge to the resistive load. When solar irradiance increases the battery start charging and the battery voltage increases, while battery voltage reaches 13.4 V battery acts as float “charge” that remarkably constant

voltage during that time present in figure (4-17), as the PV module generate electricity that charging battery simultaneously battery discharge in the loads. During charging, the region of raising voltage called bulk charging, the constant voltage region called absorption charge, and the region voltage decrease called float charge shown in figure (5.17).

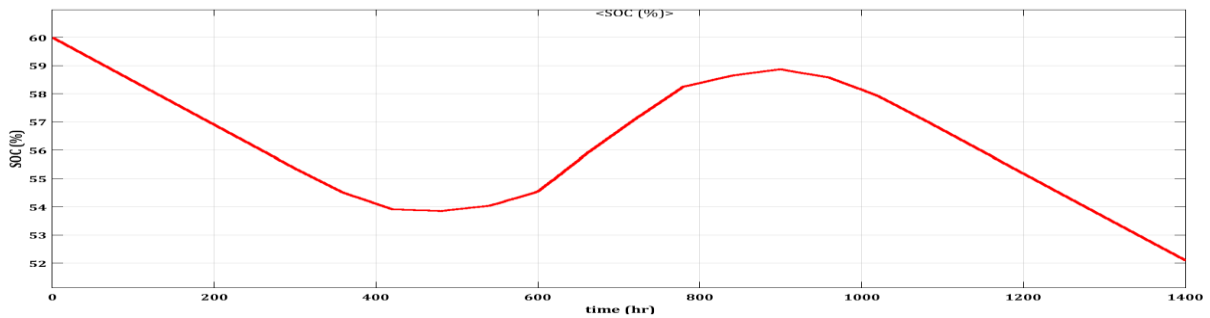


Figure 4-16: Simulation Result of SOC with a Constant Resistive Load

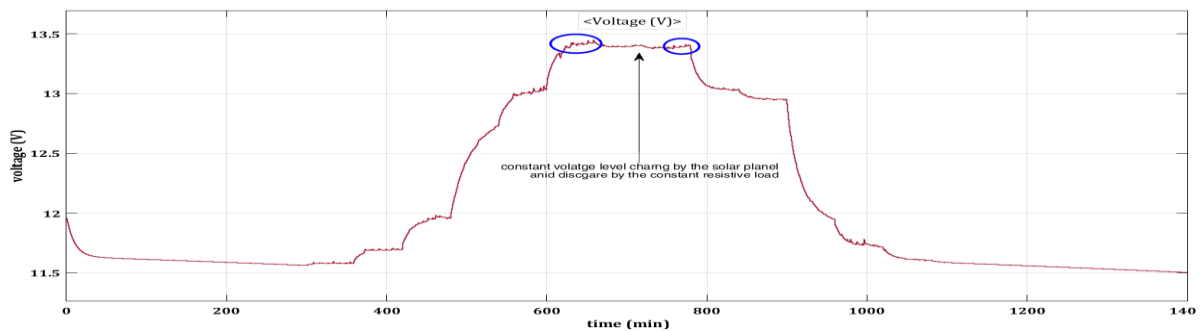


Figure 4-17: Voltage Level with a Constant Resistive Load

In the SHS or PV system present in figure (4-14), increasing the resistive loads in the system, battery discharges over the loads and the SOC level decreases 60 % to 56 % in between 00:00 h to 8:00 h, as increases the solar insolation loads not consumes power from the battery rather PV supplies power directly to the load while the SOC remains constant show in figure (4-18). While there is no solar irradiation, battery again discharge overloads and SOC of the battery decreases to 33 % from 17:00 to 24:00 h shown in figure (4-18).

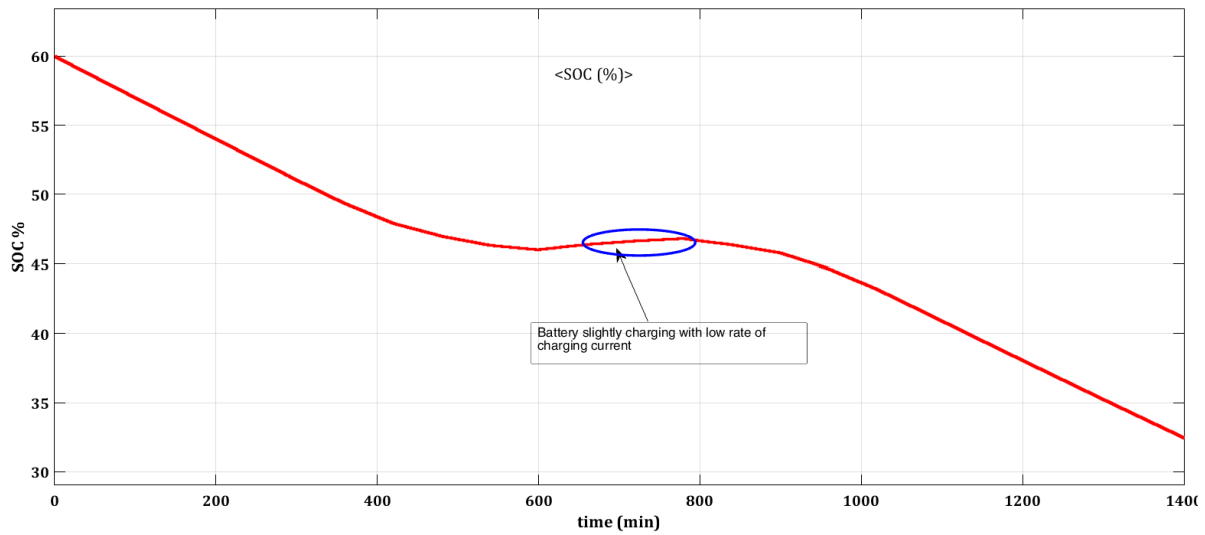


Figure 4-18: Charging and Discharging effect During Enhancement of Loads

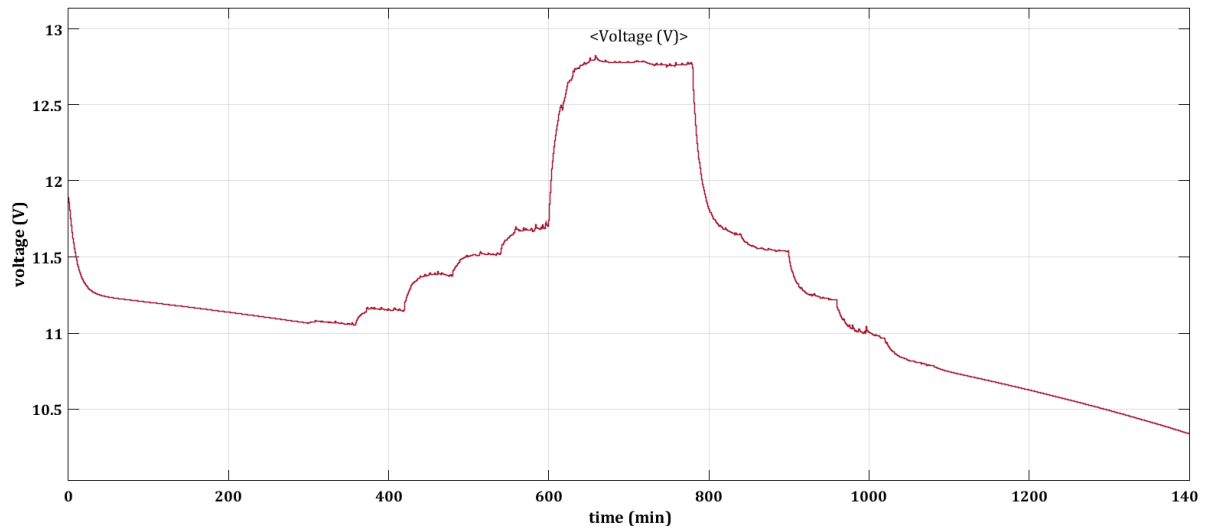


Figure 4-19: Voltage level during discharging and charging

In figure (4-19) presents, during solar irradiation increases the battery voltage increases simultaneously. At 10:00 h the battery voltage increases remarkably from 11.6 to 12.9 V while solar insolation is available, and PV power supplies to the load and battery remains constant at 12.9 V.

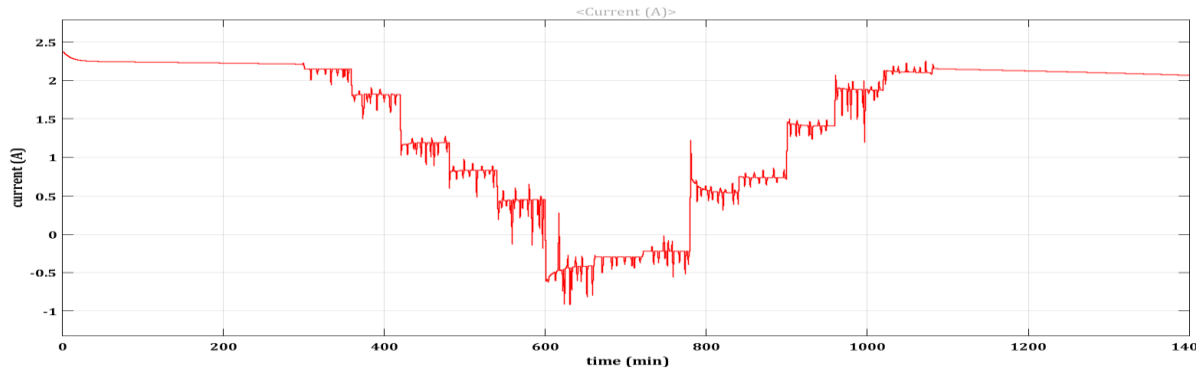


Figure 4-20: Discharging current of battery

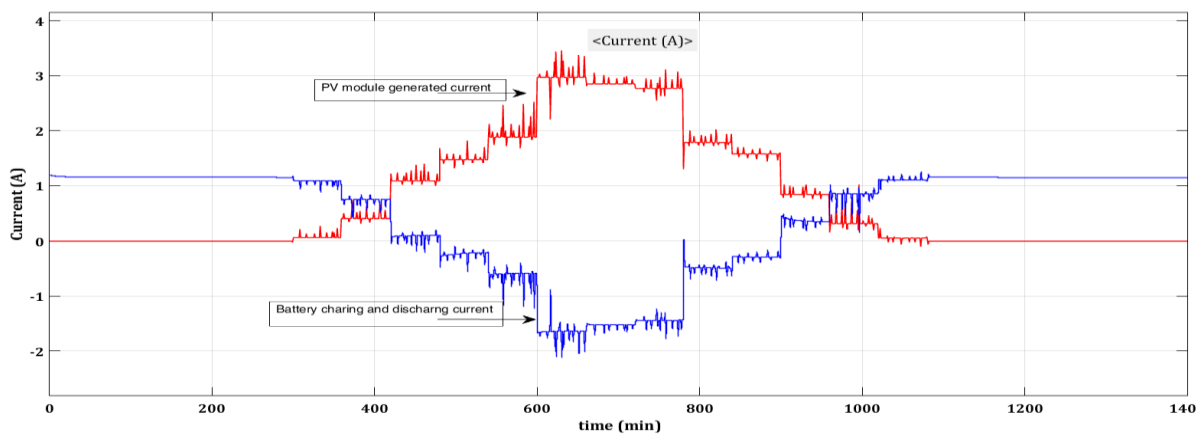


Figure 4-21: PV generated current vs Battery Charging and discharge current

In figure (4-20) and (4-21) present the charging and discharging current. The red spikes I figure 4-21 represents the PV generated current.

4.3 SHS and BHS modelling and simulation

A Solar home system connected in parallel with other battery home system, the proposed system three SHS and 2 small BHS system connected through a hub, defined a cluster According to the proposal the capacity of each medium size SHS $65 W_P$ and large $100 W_P$. A $100 W_P$ and two $65 W_P$ SHS assimilated within the common cluster figured in (3-25a). A SHS model present in figure (4-14) and a Battery home system is loads are connected within a battery. The Battery home system connected with the SHS, and solar energy shared within these including SHS and BHS.

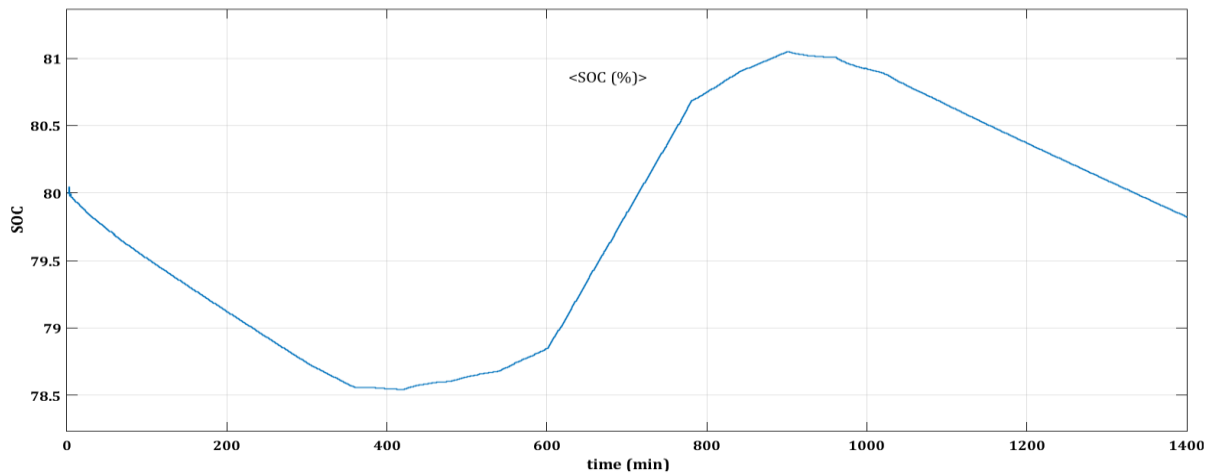


Figure 4-22: SOC of large size SHS Battery

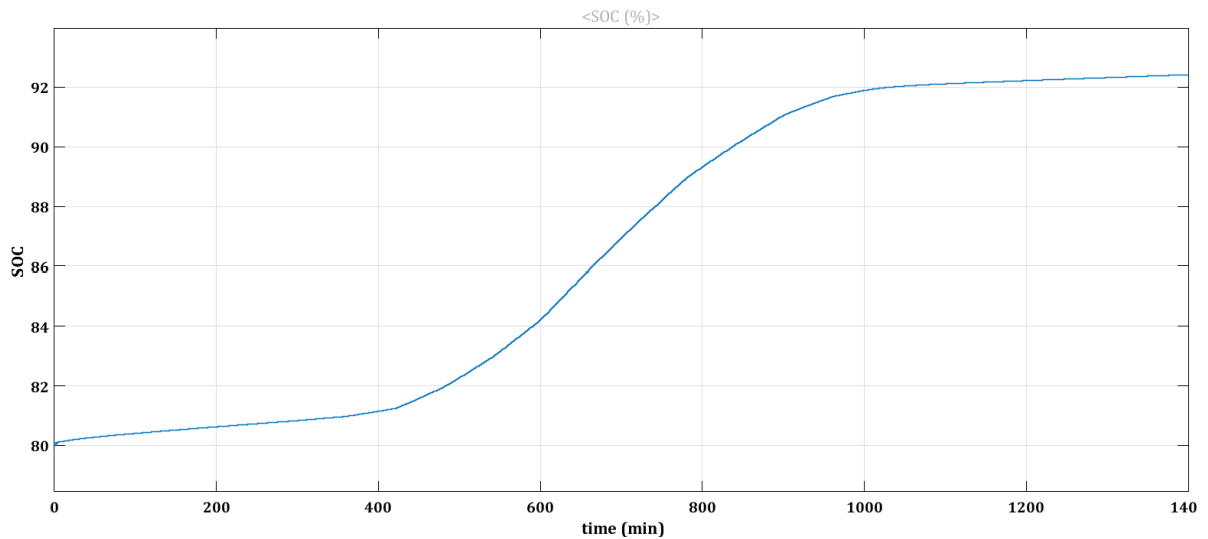


Figure 4-23: SOC characteristics of BHS

According to the proposal, a Large SHS measured as 72 cell module with characterized short circuit current 5.99 A, and open circuit voltage 21.7 V. Large SHSs are generating solar energy which is comparatively large enough to share excess solar energy among another system. From the multi-micro grid concept, where a cluster is shown in figure (3-25a and 3-25b), where two medium sizes SHS, 1 large size SHS, and two BHS sharing their energy among them. The ability to share excess energy among SHS and BHS within the cluster. Conferring to [151], many SHS do not utilize both solar energy and their battery energy, by midday the battery getting fully charged as in the rural areas electricity is not being used in the daytime. So SHS can share their energy to BHS, the system whose are

not afford Solar panel due to high cost. A small scale battery favorable for the low-income people whose can afford that battery and connected to the system.

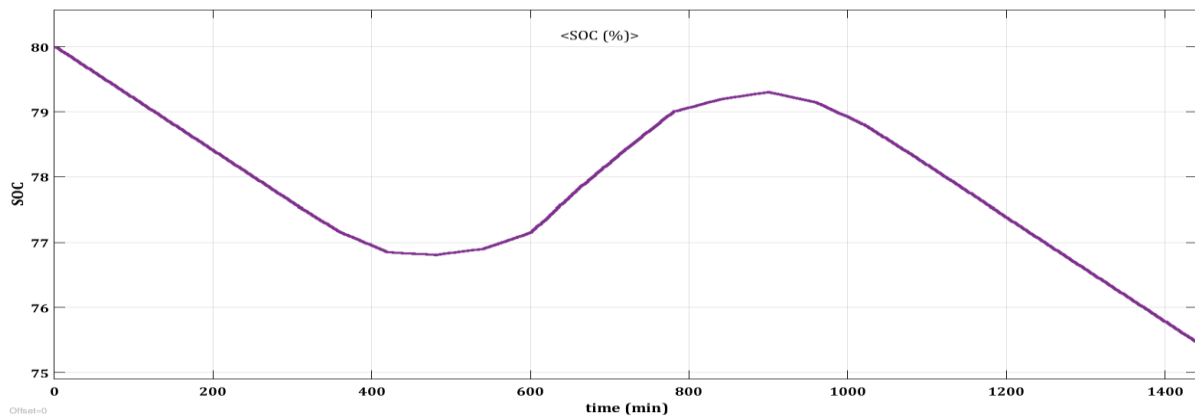


Figure 4-24: SOC characteristics of regular size SHS

A regular size SHS with less capacity than the large SHS also has the ability to charge their battery and BHS. Figure (4-23) and (4-24) represent SOC characteristics of regular SHS and BHS respectively. Comparing figures (4-22), (4-23) and (4-24) SOC of large SHS levitation higher than regular size SHS. The SOC of BHS is progressively escalating which is connected to the large size SHS compare to the BHS that connected to the regular size SHS. When BHS connected to the regular size SHS, the charging, and discharging level are analogous for both SHS and BHS perceived the SOC characteristics shown in figure (4-23) and (4-24). Also, during sun peak hour, the value of SOC of regular size SHS are not high as large size SHS comparison shown in (4-21) and (4-22). The BHS which is connected to the regular size SHS, the value of SOC much inferior to large SHS represent in (4-23). Without charge controller, the solar generated PV current (amp) also fluctuate with the solar insolation. The battery circuit designed for regular size SHS to charge 12 V, 65 Ah sealed lead acid battery, on the other hand for the large SHS 12 V, 100 Ah.

4.3.1 Charge controller modelling and simulation

Unbalanced discharging and overcharging of the battery is hazardous, and the result of degradation and corrosion of battery, which has a negative impact on battery capacity and state of health (SOH). The output constraints of the battery such as terminal voltage

VT and SOC varying on charging and discharging current. The variable charging current which are generated from variable solar insolation, and discharging current which varying on loads. State-of-charge (SOC) of lead acid battery decreases, consequently decreases of its terminal voltage. The terminal voltage about 12.6 to 12.7 V at SOC of 100 % afterward discharge, the voltage decreased to 12.1 to 12.2 V at SOC of 50 % of a typically sealed lead [152] acid battery present in figure (4-25). When the battery is completely empty SOC is 0, the voltage is about 10.5 V.

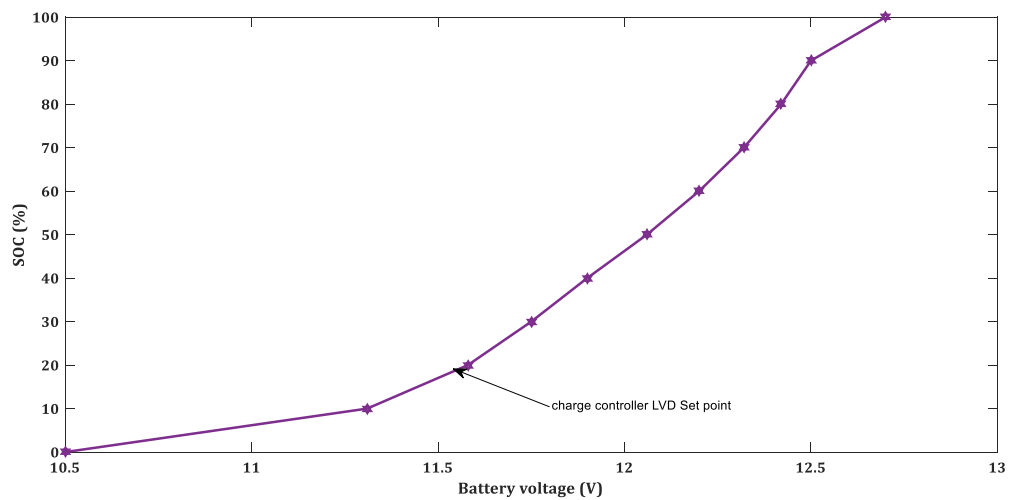


Figure 4-25: Terminal Voltage vs SOC% of Lead acid Battery

The standalone PV system, SHS, and BHS configuration, DC load is always connected with a battery as the back power of the system. With a charge controller of the PV system additional components that afford a battery and system stability. A charge controller regulates the current from PV module and prevents maximum voltage level that exceeding during charging. The output of charge controller connected to the battery through a dual cut off disconnect.

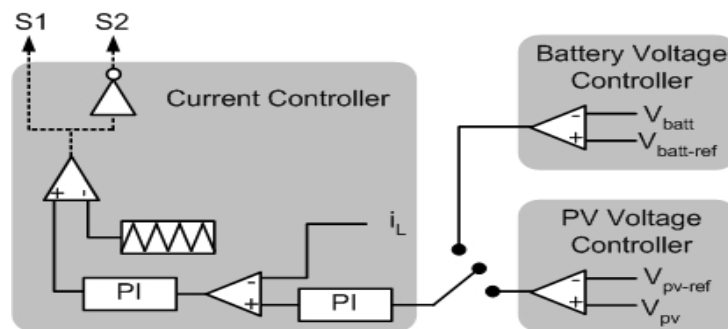


Figure 4-26: Typical Charge Controller [153]

The output of the charge controller is reference PV voltage (V_{PV_ref}) and input are including actual PV voltage (V_{PV}) and current (I_{PV}); battery voltage (V_{batt}) and current (I_{batt}) shown in figure (4-26). Measuring the Excessive battery current that flows in the battery, and typically rating of both battery and PV current which are decided the current for charging the battery.

According [153] battery charging current always less than the system current as considered. As shown in figure (4-27) battery current and voltage are distinct as $I_{batt-MAX}$ and $V_{batt-MAX}$ respectively. V_{PV_ref} and k are setting as initialized as starting. Every step the battery voltage and current (V_{batt} & I_{batt}) and PV current and voltage (V_{PV} & I_{PV}) are distinguished. The power has calculated form the PV generated voltage (V_{PV}) and current (I_{PV}). As showing in the algorithm flowchart (figure 4-27), compare the measured battery voltage and current with maximum set value of battery voltage ($V_{batt-MAX}$) and current ($I_{batt-MAX}$). If P_{NEW} lower than P_{OLD} , the value of V_{PV_ref} reversely changed. On the other hand, the value of V_{PV_ref} is further changed when P_{NEW} is higher than the P_{OLD} . Subsequently, the power reduces, the battery voltage and current also reduce. The battery voltage and currently less than the maximum set value the MPPT executed as flowchart described in an earlier chapter (section 4.3). Meanwhile, the battery voltage (V_{batt}) and current (I_{batt}) changed to maximum or above set point values then reduced the extraction of power from the PV module.

According to the proposed charge controller scheme, a buck-boost converter 12 battery and 45 W_P with ($V_{OC}=21.7$ V and $I_{SC}=3.99$ A) PV array simulate based on SIMULINK environment. The voltage changes from 24 V to 12.2 V in $t= 0.06$ sec and current change from 4.4 A to 3.80 A at no load, the result shown in figure (5.29). By using P & O method, maximum 65 W extracted from the PV module by using boost converter. Gassing voltage of the battery that used in the proposed system 14.3 ± 0.2 V. The voltage increased at 16.5 V from 12.3 V, the power elevated at 65 W. With constant voltage at 12 V, where the battery upper threshold voltage maintained across the battery current increases to bulk value for charring the battery shown in figure (4-28).

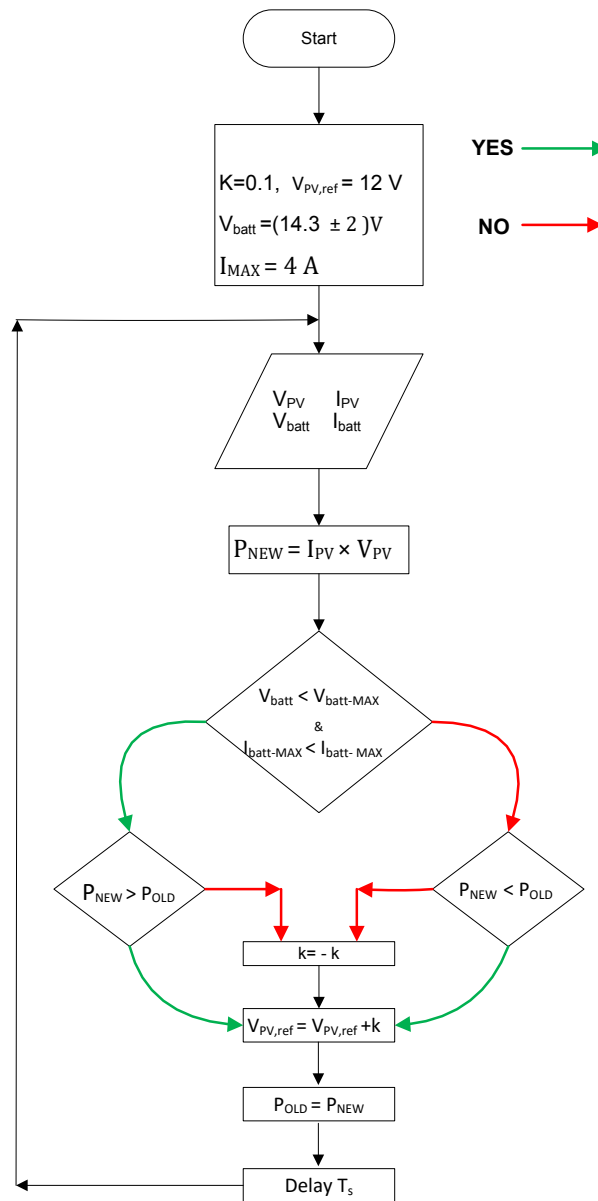


Figure 4-27: Charge Controller flowchart Algorithm

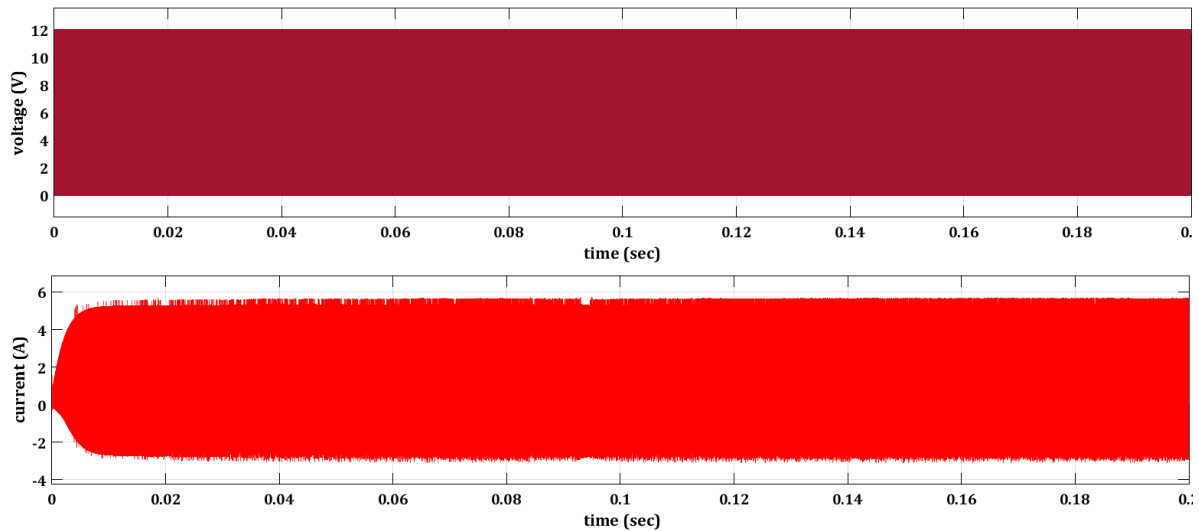


Figure 4-28: Charge controller at constant 12 V, and increased current

In constant current (CC) the converter, battery charging with whatever the variation of PV array generated PV current along with a constant current. Different solar insolation, PV panel generated power fed into the converter and charge controller then a PWM signal from charge controller supply constant current to the battery throughout the a DC - DC converter during charging process.

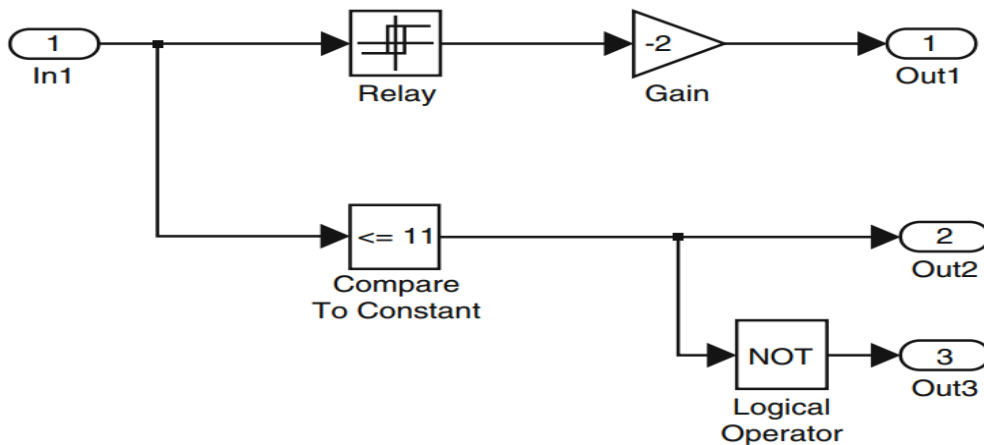


Figure 4-29: Internal Circuit of Charge Controller

The SHS design consists of PV panel that connected to the battery through charge controller, and load loads. Due to voltage control in the system both SHS and MG uses bidirectional DC-DC converter. At temperature 20 °C to 25 °C of cell temperature of PV

module about 13 to 15 V and sometimes voltages raises to 16 V during cold and high solar insolation. A convert uses to control the voltage level in the system. In figure (4-30) and (4-31) shown the SHS and PV system modelling in Simulink environment. The MPPT tracker incorporate within the charge controller that control the battery SOC and uphold the battery health and life. However, charge controller On/Off followed by the SOC of battery; i.e. MPPT turns off while battery full otherwise operate in on state.

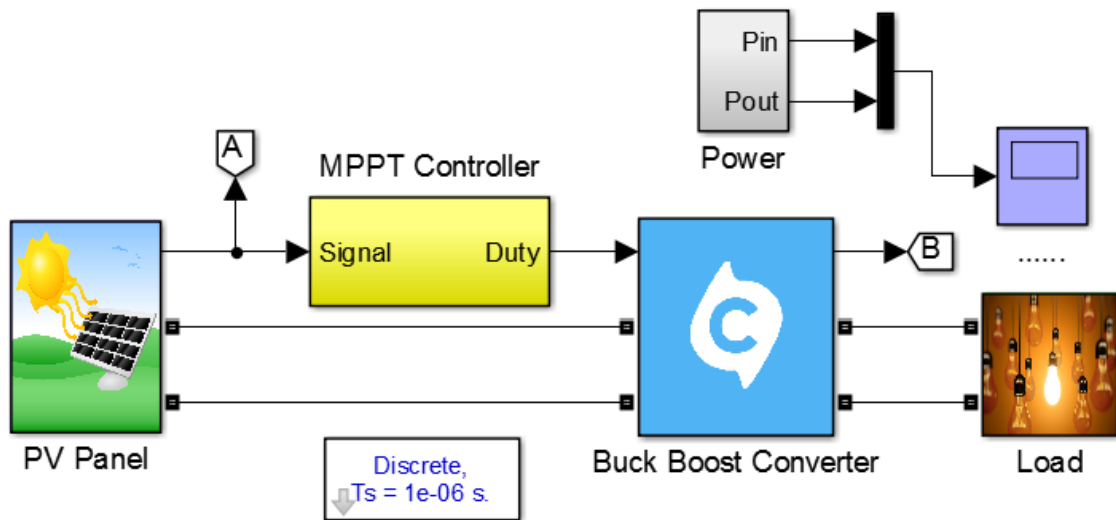


Figure 4-30: Complete SHS with charge controller

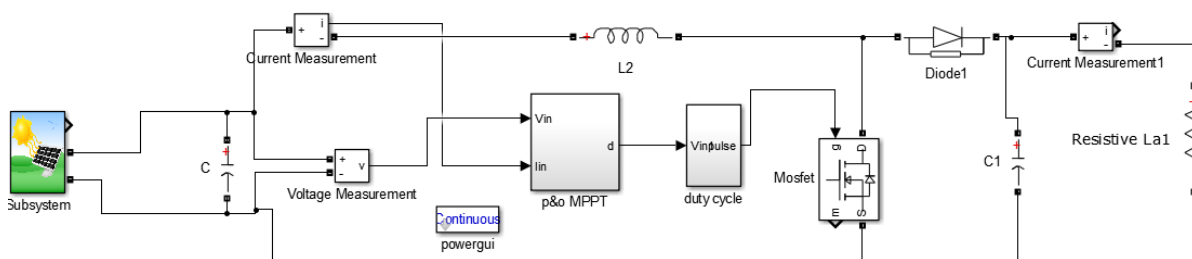


Figure 4-31: PV system connected by MPPT and boost converter

Constant voltage charging scheme, amount of charging current regulated by the charge controller, as set VR maximum set point voltage. In practice, charging the battery with whatever the PV current generated by PV array until VR set point. As voltage increases the current also increases, controller prior to limit the maximum current by switch to constant voltage. The limiting shaped current at constant voltage controller passes as charge current that controller does not force more current into the battery. To protect

overcharge settling VR point up or down. Although setting VR set point is difficult and complex, as high VR set point battery will have overcharged often, and low VR set point battery will never fully have charged. The occasional full charge called “equalization charge”. For optimal charging, equalization charging phase has performed in non-sealed wet battery. Equalizing phase has a chemical effect such as stratification on the battery plate. By increasing 5 % of charge voltage over nominal voltage overcharge equalize and balance the voltage and specific gravity [154]. Any lead-acid battery cell above 2.15 V per cell, 12 V battery charging voltage above 12.9 V. however, the higher voltage used to forcefully charge a battery within short period of time, but with a low voltage charging will take longer period time than high voltage.

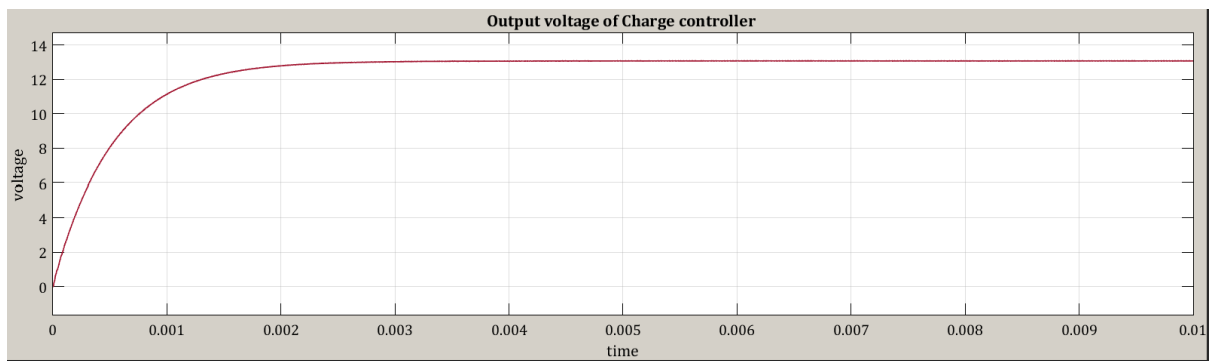


Figure 4-32: Output PV voltage controlled by MPPT charge controller

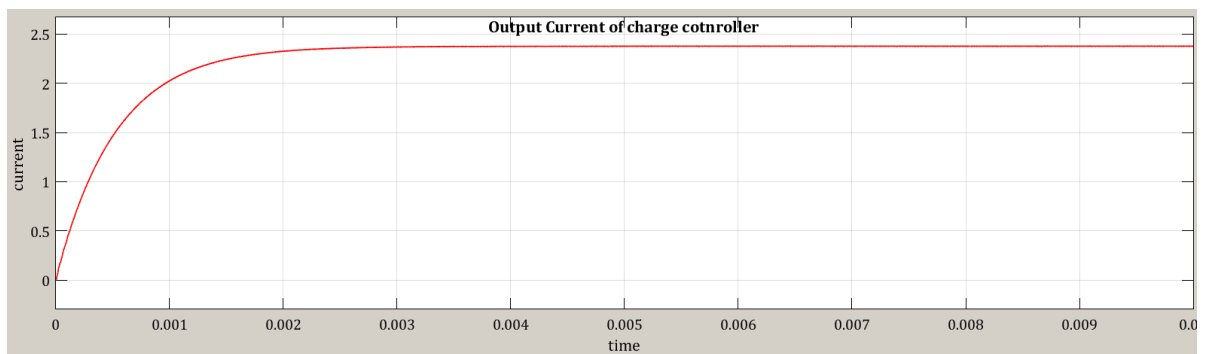


Figure 4-33: Output PV Current in MPPT charge controller

As show in figure, (4-32) and (4-33), the output voltage and current about 13 V and 2.4 A current at cell temperature 25 °C with regular solar insolation about 450 W/m². By using P&O method, it is contingent that the output voltage with achieved as desired. The

changing of solar irradiation, output voltage oscillate around the maximum power point (MPP), the output charge controller voltage increases as shown in figure (4-34).

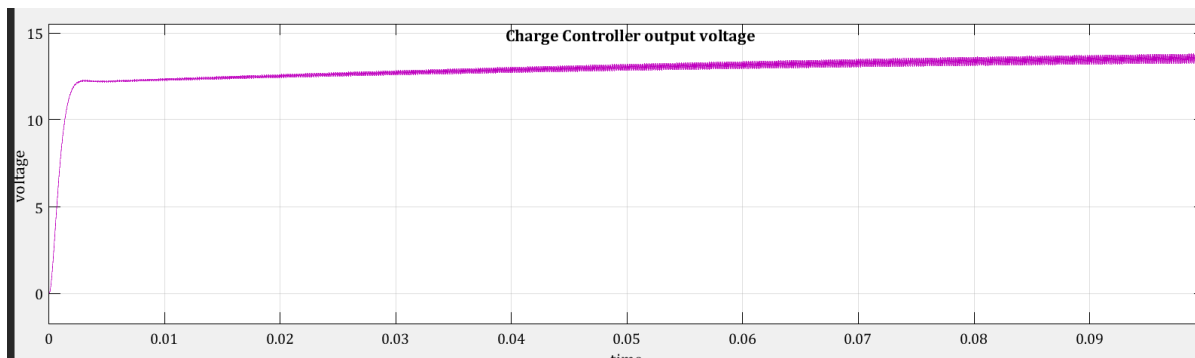


Figure 4-34: Output Voltage as increases solar insolation

The amplitude of voltage of voltage increases which is depends on reference voltage considers $V_{ref} = 12\text{ V}$, and at constant solar irradiation MPP voltage also depends on reference voltage. In the system a bidirectional Dc-DC converter used as shown black box in figure (3-26a and 3-26b); SHS to DC bus converter act as boost converter, otherwise act as buck converter. In figure (4-35) and (4-36) presents the boost converter output, when the voltage raises about 16.6 V and current 3.9 A.

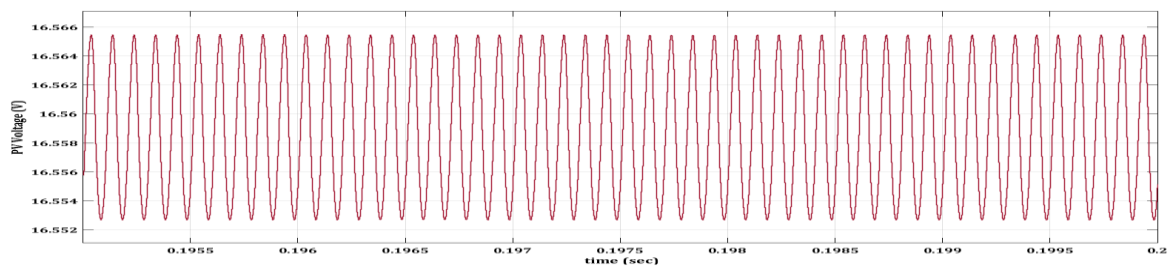


Figure 4-35: Boost Converter output voltage

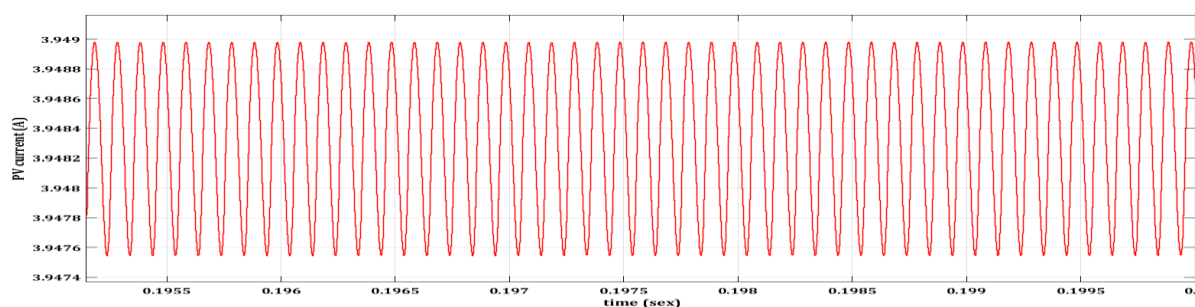


Figure 4-36: Boost converter output current

4.3.2 DC - DC Converter

Converting the power between PV panel and DC bus, the converter operate buck or boost mode followed by PWM signal show in figure (4-42) and (4-43), whereas S1 and S2 switch controlled PWM. The charge controller operates continuously when PV module still generate low value of PV current, the boost converter will boost the low level of current during less solar insolation up to the maximum charging current for charging the battery. Figure (4-35) and (4-36) depicted the output current and voltage of boost converter. A non-isolated type DC - DC converter used for each SHS instead of transformer or other FACT decides for stable the desire voltage, current in the system. The converter with MPPT in the SHS to regulate the output voltage of the PV array. The variable solar insolation generated inconstant voltage change to 12 -24 V.

The DC - DC converter, on-state input voltage source from PV array directly connected to the inductor (L) and the energy gathered, the capacitor supplied the output voltage (V_0) that is connected to the battery. In the off-state, accumulated energy from the inductor to the battery or load and energy transferred from inductor L to capacitor C and resistor R. The output voltage

$$V_{out} = \frac{D \times V_s}{1 - D} \quad 4-3$$

$$D = \frac{V_{ref} - V_s}{V_{ref}} \quad 4-4$$

Where

V_s	Input Voltage
D	Duty cycle
V_{out}	Output Voltage
V_{ref}	Reference voltage

Switching mode step up DC - DC converter, the output voltage depends on source voltage from PV, the output voltage (V_{out}) related on duty cycle as switch. The regular SHS solar panel at 45 W, the power/W is equal to the voltage (V), required current is maximum 3.5 A times 12.24 V = 45 W_p. And Large SHS 65 W, required maximum current 4.9 A times

12.3 V= 61 W. According to the proposed MG, the system considered 12 - 24 V. In practice, the on-state $D \geq 0.5$ and off state $D \leq 0.5$ suggested in [155].

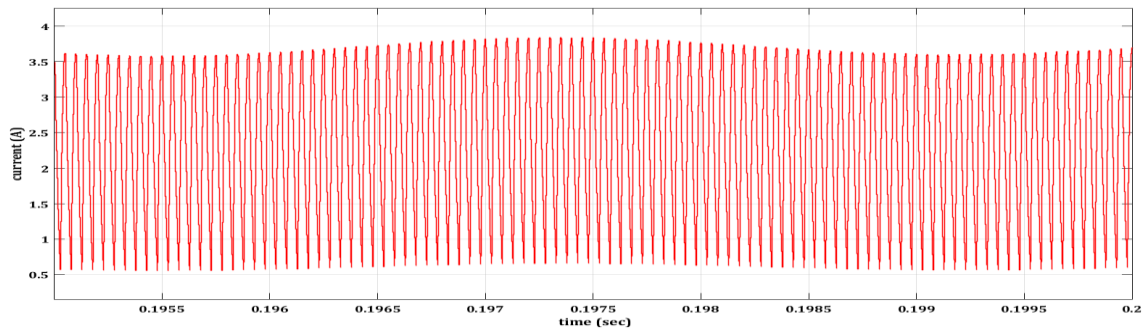


Figure 4-37: Converter Current @ buck converter mode

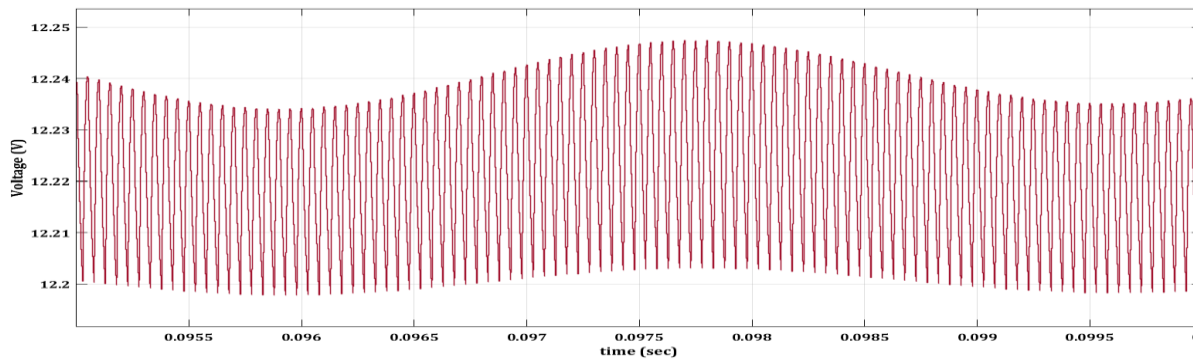


Figure 4-38: Converter voltage @ buck converter mode

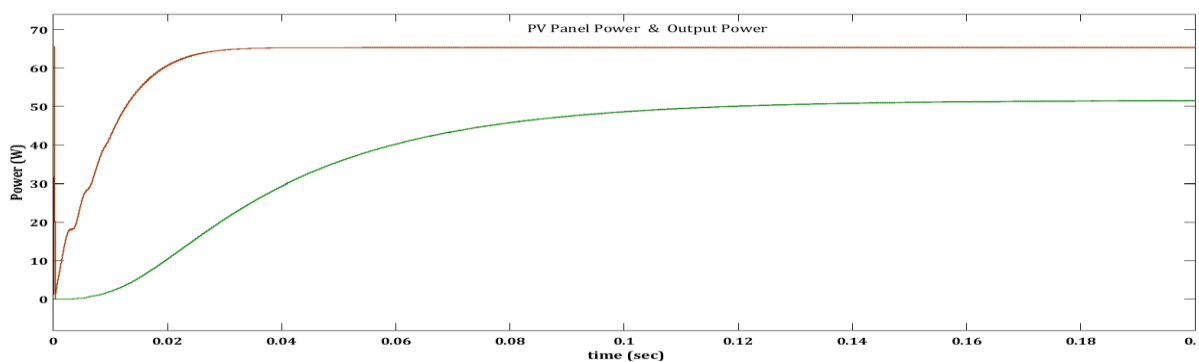


Figure 4-39: input power and output power (regular size SHS)

In figure (4-39) and (4-40) present the both power including buck mode power represent by green line, and red line represent the boost mode power. As shown in figure (4-37) and (4-38) the output of current and voltage in buck mode. In figure (4-39) and (4-40)

represent the power of large SHS and regular size SHS output power; the green line represents output power of generated by the PV system, and magenta colour represent the output power converter delivers to the MG system.

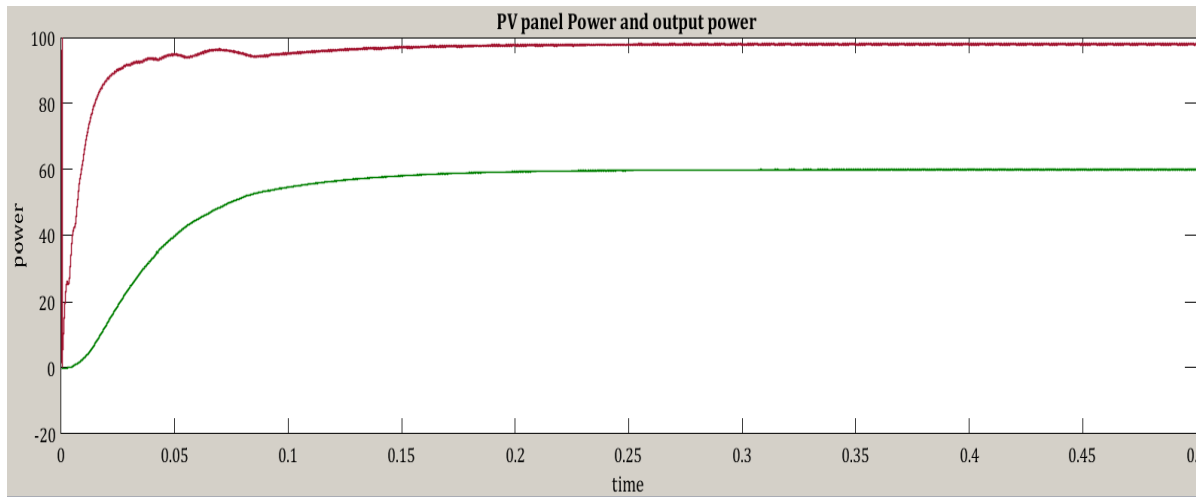


Figure 4-40: Input power and output power (large size SHS)

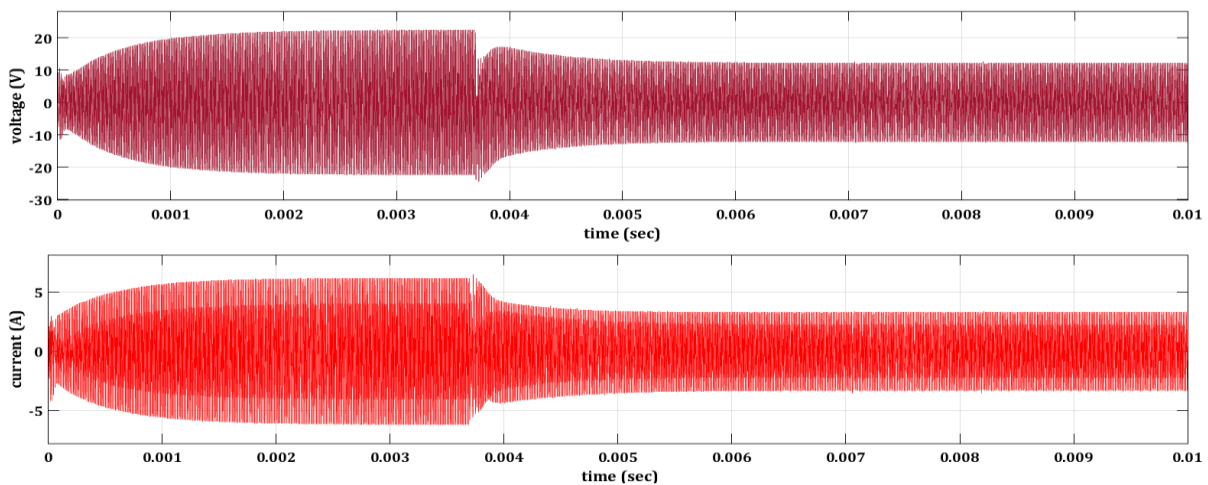


Figure 4-41: Busk-boost converter output

The charge controller incorporate with MPPT which controls the duty cycle of buck converter, the supplied voltage use input voltage of converter and output voltage supplies to the battery, the design show in figure (4-30). The converter operate at very high frequency 10 kHz, in practice converter designs to exchange power level on the system.

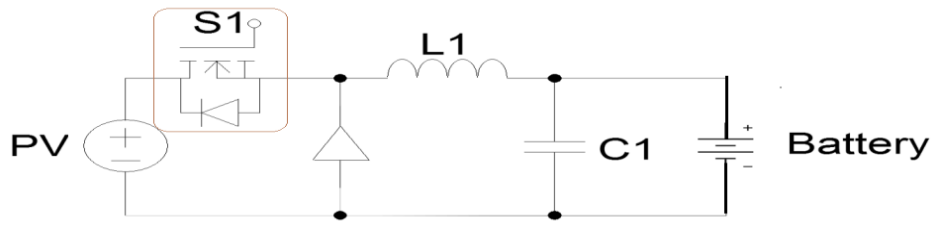


Figure 4-42: Schematic design of Buck converter

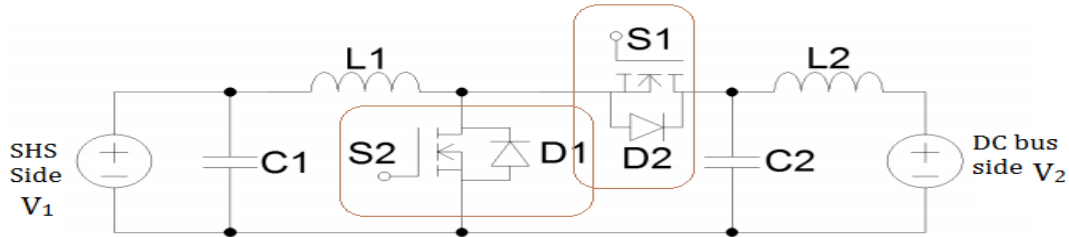


Figure 4-43: Bidirectional Buck-Boost Converter

12 V or 24 V DC system use in the proposed scheme for exchange power between SHS and DC bus, in practice the voltage comparatively higher than 12 V DC which reduces the system losses and increases the distribution system. The scheme proposed a 24 V DC bus system, which standard encouraged by Emerge Alliance also used 24 V protocol offers stability and reliability. The converter used among all SHSs, transforming 12 V/24 V in the system whereas 12 V used as the terminal voltage of the battery. The DC bus considered a common bus, among all SHS connected in the system while maintaining the proper voltage level in both sending and receiving power autonomously without any centralized MG controller. In figure (4-41) represent the output of converter used in the system, whereas the converter simulation act both buck- boost mode, in boost mode simulation result shown about 22 V and 5.3 A while buck mode about 12 V and 2.8 A. The bidirectional DC-DC converter $V_1 < V_2$; L_1 , D_1 , C_1 , and S_1 parameters define the stand arrangement of buck converter shown in figure (4-43) correspondingly L_2 , D_2 , S_2 and S_2 desalinate the standard parameters of boost converter. The switch S_1 and S_2 control by the PWM controller shown in figure (4-44), PWM controller controlled by the MPPT duty and switching frequency.

Table 4-2: Converter Switching frequency varies with inductor and capacitor

Switching frequency	10	30	50	100	150	300	500
L1 (μH)	47	8-10	5.5	2.5	1.8	1.3	0.5
C1 (μF)	200	80	50	25	17	8	5

The parameters L_2 exertion with C_2 present in figure (4-43) to form of a second order filter or EMI filter for boost converter. The corresponding DC-DC converter, it is essential to control together for appropriate and reliable operation. In this context, the switch S_1 and S_2 should never be on at the same time in the operation, while S_1 operates at duty cycle calculated by the ratio of V_1/V_2 , and S_2 operates with balancing signal the completing no power exchanged in between V_1 and V_2 . When increases the duty cycle ratio of (V_1/V_2) and decreases duty ratio of S_2 instantaneously converter operates in buck mode while transmit power from V_2 to V_1 . Contrariwise, in the boost mode operation S_1 set at slightly higher duty ratio than previous of V_1/V_2 and adjusting S_2 duty ration consequently, power transmit form V_1 to V_2 . The different power level of both large size and regular SHS separately represents in figure (4-39) and (4-40). The boost converter can be design by using different switching frequency which varies with different L_1 , C_1 , C_2 , and L_2 presents in table (4-3). The buck converter parameters countless PWM switching frequencies for operation expending 20 % of current ripple, 10 % voltage ripple, and 25 % safety margin considered.

Table 4-3: Converter Switching frequency varies with inductor and capacitor

Switching frequency	10	30	50	100	150	300	500
L_1 (μH)	120	80	46	28	17	8	3.6
C_1 (μF)	33	19	12	5.3	3.2	1.8	1.2
C_2 (μH)	250	120	54.3	27.1	19.2	8.9	5.2
L_2 (μH)	78	49.2	29.3	14.4	8.1	4.2	3.1

The MG operation, where SHS and BHS operate through bidirectional converter in the same bus coupled in parallel and the elements (SHS and BHS) which supplies and receives power. With higher SOC, the equation (4-5) calculate boost voltage. Where SOC_{SHS} define by the state of charge SHS, $\text{SOC}_{\text{Sharing}}$ represents limits of sharing set by the SHS owner,

V_{Syst} defines battery operating voltage, and K is the scaling factor; K measures by the value of surplus Wh available for sharing. In practice V_{offset} and V_{Syst} setup by 24 V and 12 V respectively. The scaling factor set as 200 to 300 Wh (watt-hour), and $\text{SOC}_{\text{Sharing}}$ scaling up to 50 %.

$$V_{\text{boost}}(n) = V_{\text{offset}} + \frac{(\text{SOC}_{\text{SHS}}(n) - \text{SOC}_{\text{Sharing}}) \times \text{Batt}_{\text{Ah}}(n) \times V_{\text{Syst}}}{K} \quad 4-5$$

In the system, each SHS connected through an individual converter to the bus of its point of common coupling (PCC), while each of the converter control voltage of PCC to achieves to V_{boost} , and then the bus voltage V_{bus} roughly equal to the V_{boost} .

4.4 MG Modelling and Simulation

In the proposed MG, the system design as show in figure (4-45) where both large size and regular size SHSs connected through DC - DC bidirectional converters to the MG. The BHS system connected in the system without any converter, the battery coupled with the MG bus through charge controller.

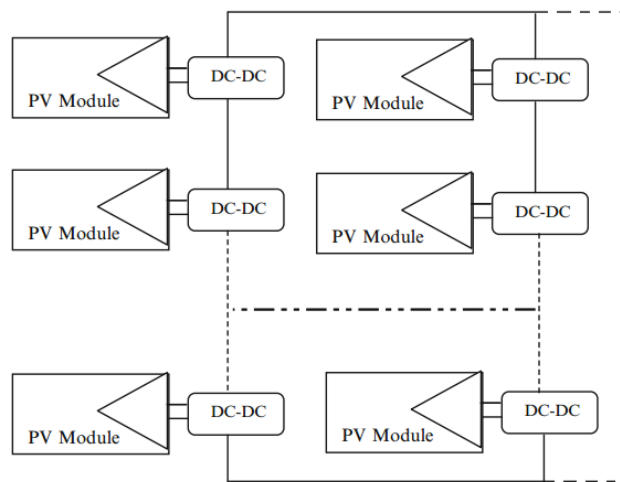


Figure 4-44: Schematic diagram of the system integrated individual DC-DC converter

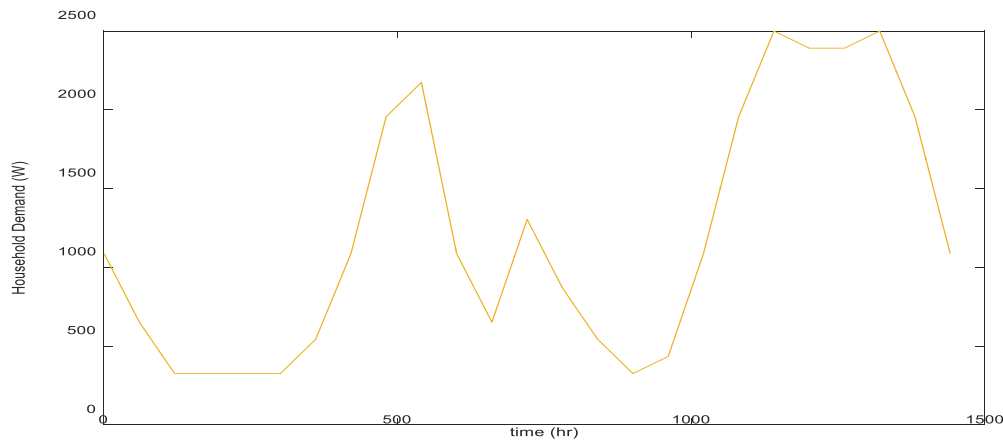


Figure 4-45: Household demand on 31 June, 2013

In the MG both large size and regular size SHS and BHS integrated in residential community defined as the cluster of energy producer and consumers shown in previous chapter figure (3-22). When these clusters are connected in a DC bus and sharing their generated energy called MG. The purpose of this community based MG to sharing energy, best utilization solar peak hour, energy consumption cost of the community rather purchasing electricity from the national grid. Three SHS (1 large size SHS, and 2 medium size SHS) connected in parallel in common hum called cluster described in multi cluster MG, connected cluster in a common DC bus called MG. the proposed MG operate in standalone mode and grid mode. Aiming with increasing the maximum PV generation and utilization among SHS and along BHS integration proposed MG considered to connect to the national grid. PV panel, battery, grid connection, and household loads are coupled through dedicated converters, and whole MG cluster accomplished on a common DC bus. Standalone mode, PV generation for DV loads within less than 0.5 km, avoiding conversion, and absence of reactive and harmonic. The traditional MG with PV is considered a source controlled MPPT algorithm.

CHP modelling s not consider inside the MG, as CHP connected in the AC network side, but the CHP integrated system optimization describe in the next chapter by using HOMER Pro software.

The system consisting of AC grid and SHS and BHS incorporated DC network shown in figure (Appendix-1). The DC network connected to the AC existing grid via substation,

where a pole mounted transformer used (6.6KV/200V). DC MG configuration and modelling features as described below;

PV module (SHS) generates the power and used as primary source of MG. The battery of SHS and BHS stores energy, the excess energy generated from SHS is the source of energy for BHS.

- The distribution network comprises in low voltage level.
- SHS and BHS connected to from ad-hoc MG

According to the design and modelling the solar panel generated DC current at a constant voltage 12 V. The PV panel mounted SHSs which are integrated within MG, the panels' generated total power varied by solar insolation. Conferring to the SIMULINK simulation, from 11:00 h to 15:00 h with high solar irradiation 12 SHSs including (large size and medium size) produced 3.5 to 4.3 kW and 20:00 to 5:00 h generated power form SHS is 0 W shown in figure (4-47). The AC network simulated with DC MG, total battery for the whole system considered 1200 Ah (each SHS and BHS mounted with 60 Ah capacity of lead acid battery). On DC Side, house loads and battery SOC (state of charge) indicate the load consumption and battery storage level respectively. The batteries in MG able to charge/discharge when SOC range varies $SOC_{MIN} \leq SOC \leq SOC_{MAX}$, where the SOC_{MAX} is maximum value of SOC and SOC_{MIN} presents the minimum value of SOC for the battery storage system operation. According to the proposal battery charge status $SOC_{MAX} = 80\%$ and $SOC_{MIN} = 30\%$. The proposed system assumed, that the energy storage charging moderately operated by PV generation. During "day time" 23:00 h to 18:00 h battery storage by charging with to high PV generated current, and night time battery discharge by the peak load between 19:00 h to 23:00 h.

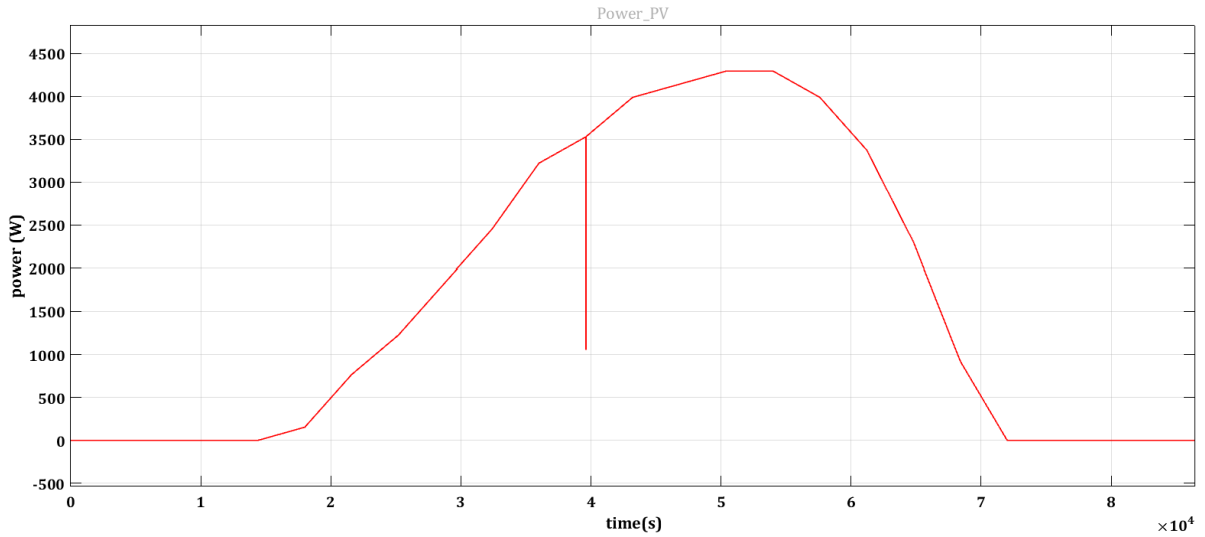


Figure 4-46: Total PV_Power generation (11 SHS, 30 June 2013)

The state of charge initially set at 80 % shown in figure (4-51), to prevent the over-charging and over-discharging in operation conditions, the Energy management system and smart home energy management maintains SOC between $30 \leq \text{SOC} \leq 80$.

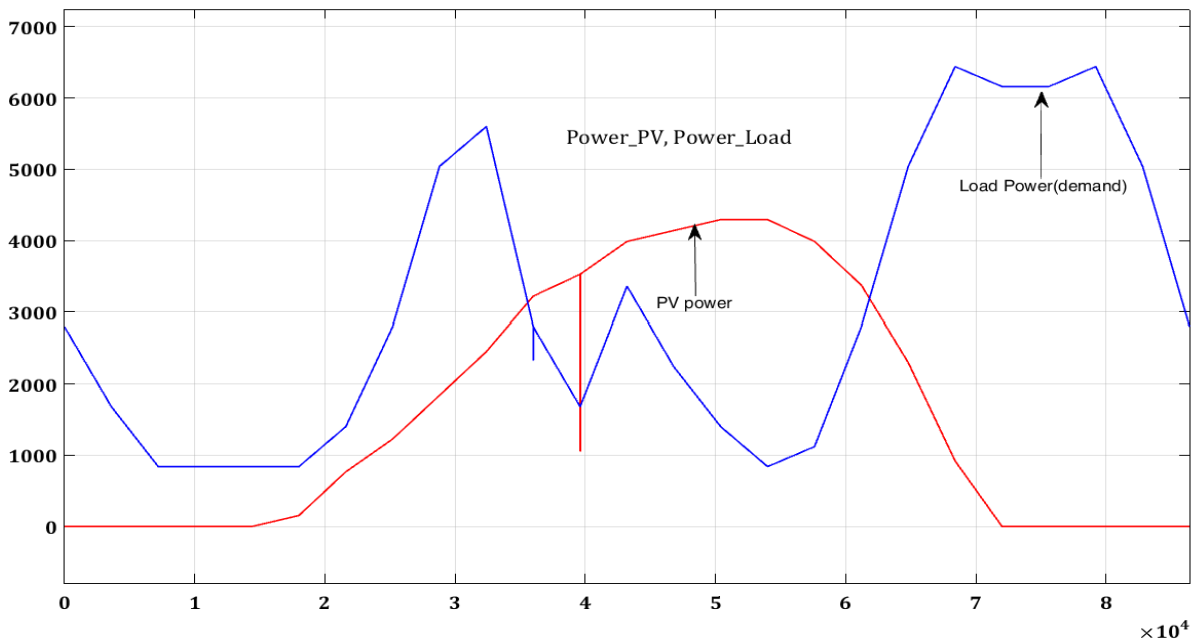


Figure 4-47: PV generated Power and load power (demand)

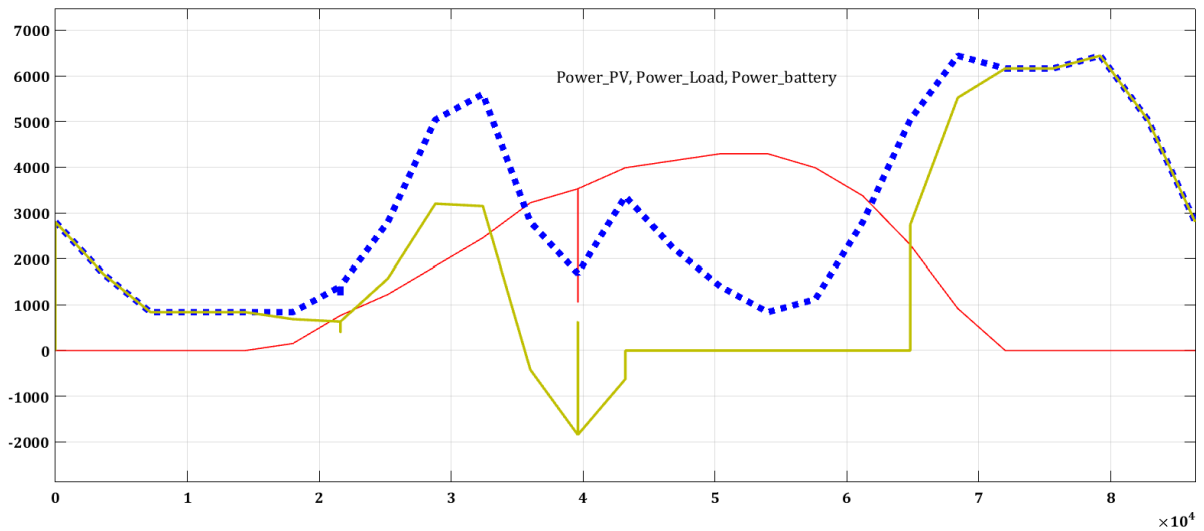


Figure 4-48: PV generated Power, Battery consumed power and Load power (demand)

In SIMULINK simulation according to the demand and solar insolation on 30 June 2013 PV-generated power is delivered to the load. PV-generated power is enough to comply the load power (the demand of 20 households) from 9:30 h to 17:00 h, but at evening 18:00 h to 9:00 h solar power is not enough to delivered power to response households demand. Represent in figure (4-48) and (4-49) during 18:00 h to 10:00 h solar power were not enough delivered to the load, and grid power and battery power compensated the power gap between solar power and load (households demand). Battery delivered 100 % power consumed by the load (blue dotted line represent the demand and gold line represent battery power shown in figure (4-49) from 20:00 h to 5:00.

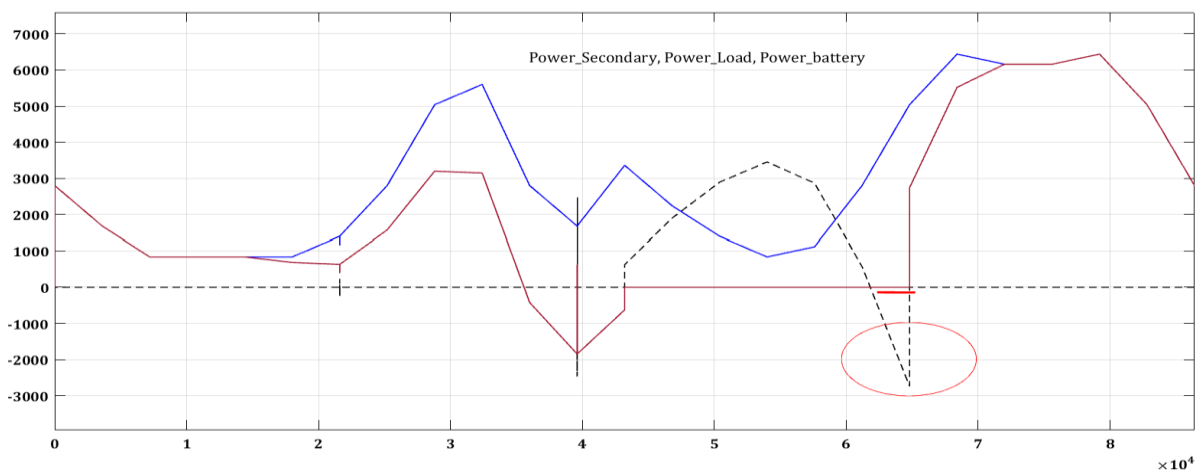


Figure 4-49: Load Power, Battery Power and Grid power

Battery delivered 100 % power consumed by the load (blue dotted line represent the demand and gold line represent battery power shown in figure (4-49) from 20:00 h to 5:00 h. Due to high PV generation, in the “day time” load power (demand) is lower than PV generation, and the battery does not use. The shoulder price (off peak) of utility grid considered from 6:00 h to 18:00 h, MG preferred to the consumed power form utility grid. According to the proposed MG, the excess power generated from the PV both supplies to the household (load power) and grid simultaneously. As shown in figure (4-52) from 12:00 h to 17:20 h, the excess power categorized between solar power represent in the red line (PV_{power}) and demand represent in blue line (load power) shown in figure (4-50). As battery controller kept as not in operation for charging/discharging and the surplus power which is not being used in the MG supplied back to the utility grid.

The main circuit break (CB) of MG is connected to the utility grid shown in proposed MG model present in (Appendix-1), in grid connected mode 12:00 h to 18:00 h grid offer shoulder price (off peak). But 17:30 h load power (demand) is increasing as household peak demand, in that time grid power consumed by the load. After 18:00h, battery power consumed by the load power present figure (4-49), and battery start discharging shown in figure (4-51). During 0:00 h to 12:00h and 18:00 h to 24:00 h battery controlled by the battery controller. Between 12:00 h to 18:00 battery controller set as “off operation”, as SOC of the battery constant and does not charge and discharge shown in figure (4-52). This battery is considered a community storage in the MG.

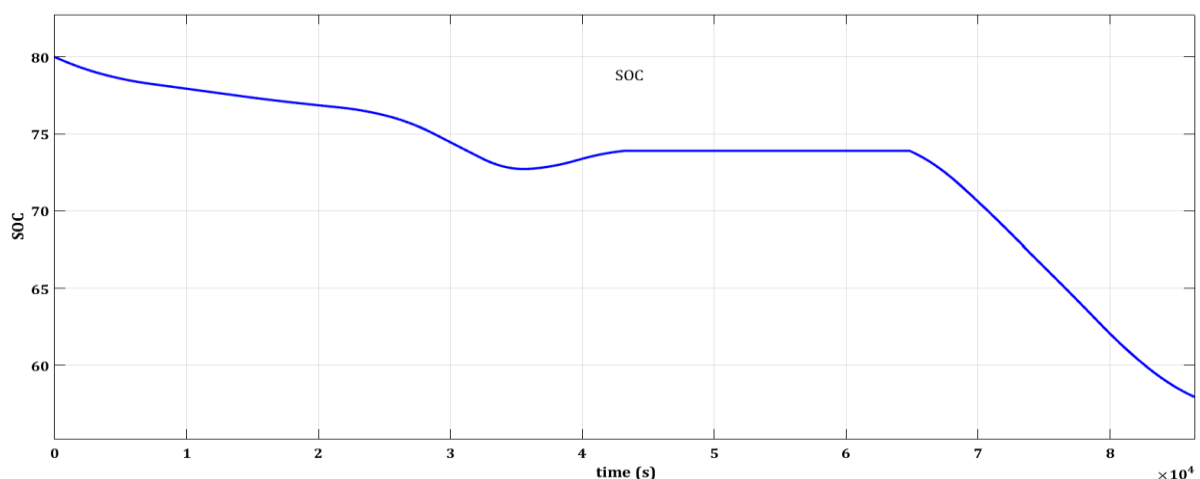


Figure 4-50: the state of SOC of MG



Figure 4-51: PV power, Load Power, grid power and battery power

The secondary power flow from the grid to the as swing load. The grid considered as stiff source of power, and facilitates stable operation for the MG. Assumed a typical day, when PV is not generated enough power to execute the charge operation to charge batteries of SHS, and grid delivered to the power load. As utility grid is considered available to take care of load in the MG, when PV is not generated and battery capacity is almost critical level. The magenta line shown in figure (4-53) which is represent power load (demand) and blue line represents similar load consumed by the 20 neighbourhood households loads, the secondary power delivered from the utility grid. The utility grid is an ideal constant voltage source considered as (66 KV) of three phase AC and frequency of AC cycle set at 50 Hz connected to the MG through pole mount transformer.

In the proposed MG, if the battery controller also considered to charging during grid tied mode; during daytime load power is lower than and battery not allowed to charge by grid, hence battery charging by the solar power present in figure (4-54) and the battery Controller designed as math function in SIMULINK environment presents in (Appendix-2). The batteries coupled in the MG, the SOC level has increased from initial 80% to 91%, and electricity supply to the load simultaneously. And the surplus electricity considered according to the algorithm strategy over 90% of SOC and the produced electricity sellback to the grid.

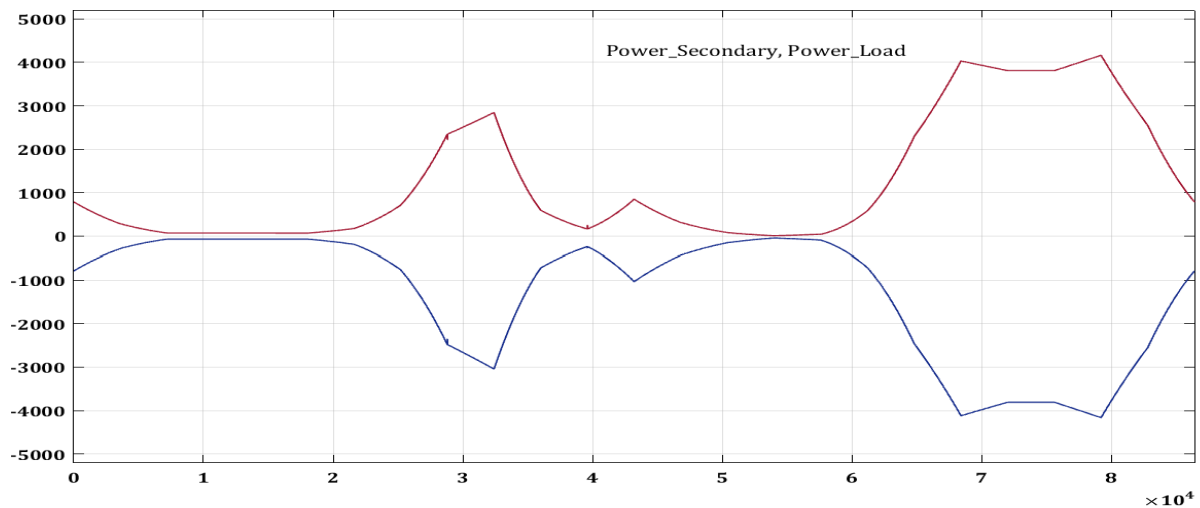


Figure 4-52: Load power vs Grid power

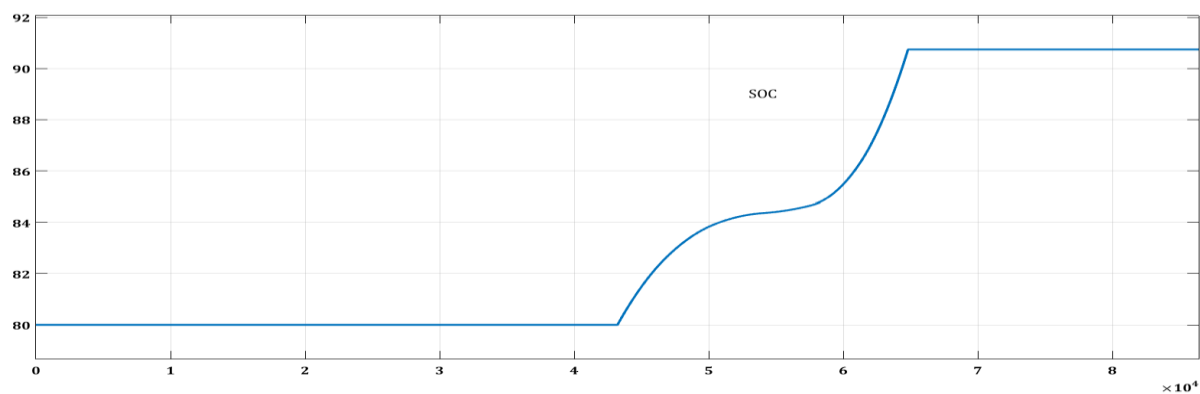


Figure 4-53: Battery SOC during charging

4.5 Control Strategy of MG

Small scale PV generation and effective advantages of power electronics MG are able to operate both grids connected and standalone mode. As the proposed MG consisting of SHSs and BHSs, individually control those are complex in operation. Each SHS operate with the smart home energy management system (SHEMS) and control strategy required for stable and reliable operation in MG. The MG primary source of energy is PV generated current, and power system is configured as DC bus. In the system, SHS and BHS are connected in parallel in DC MG shown in (4-55). The components in MG associated in parallel through power electronics module such as DC-DC converters, the system suggest several advantages including control and maximum utilization of DES power [156].

Agreeing with [157] master-slave and voltage droop controller suggested in MG operation.

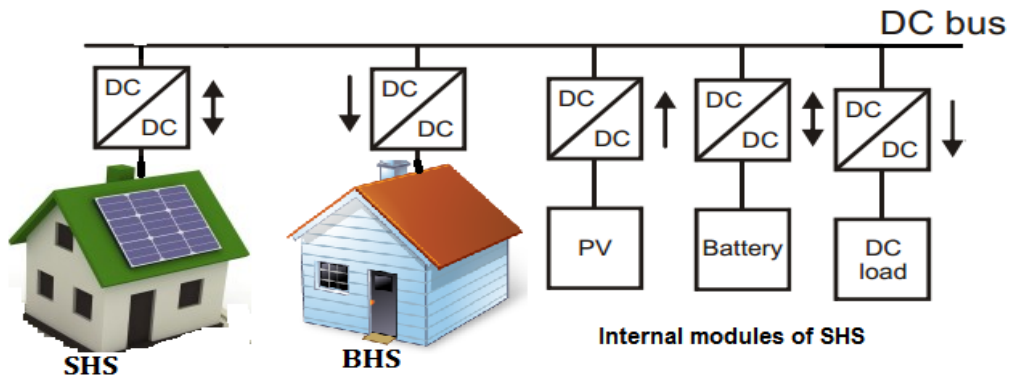


Figure 4-54: Proposed SHS and BHS connection through DC-DC Converter

4.5.1 Master-Slave MG Control

In figure (4-56) represent the master-slave control arrangement, where each SHS composed as DC source of power, a DC - DC converter, and controller. The top SHS illustrates in the figure (4-56) act as master and others operate as slaves. The Master module controls DC bus voltage, whereas slave controlled by the reference current (I_{ref}).

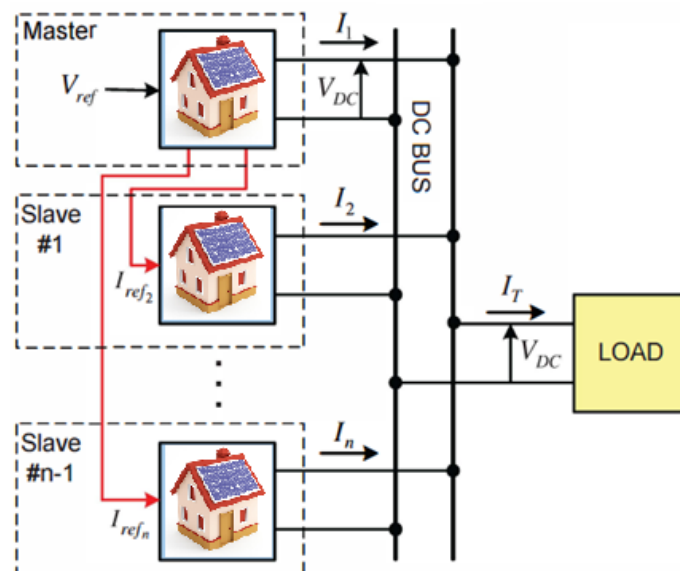


Figure 4-55: Typical Master-Slave control Strategy

In the proposed MG, Master-slave control strategy used among all SHS. The master slave control strategy proposed in the system when MG operate in the standalone mode. But the MG also operate in the grid tied mode, as controlled voltage also considered under the MG control strategy. The Reference current determined by the equation (4-6), where K = droop gain expressed in equation (4-8), V_{bus} = DC bus voltage, and V_{ref} reference voltage. The reference current I_{ref} in equation used as the input current of hysteresis current controller shown in figure (4-57)

$$I_{ref} = K (V_{ref} - V_{bus}) \quad 4-6$$

$$I_{ref} = \frac{P_{ref}}{V_S} \quad 4-7$$

$$K = \frac{1}{R_{droop}} \quad 4-8$$

$$V_S = V_{OC} - \frac{1}{K} I_S \quad 4-9$$

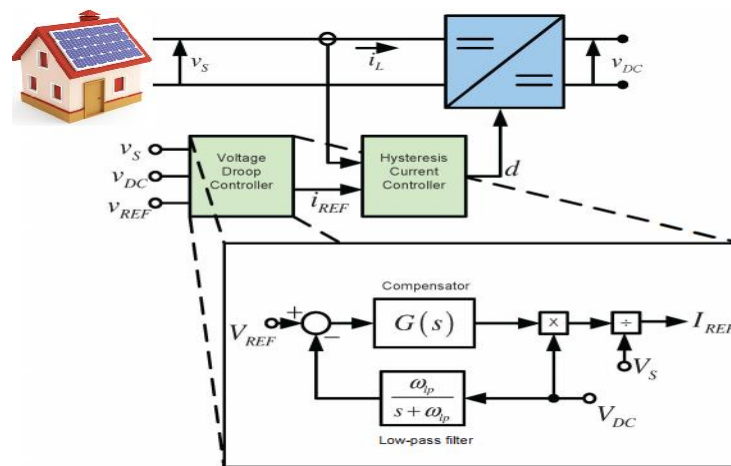


Figure 4-56: Schematic diagram of Voltage control over DC-DC Converter [158]

The local control (individual controller of each SHS) composed with DC - DC converters, autonomously share load current by detecting DC bus voltage shown in figure (4-57). According to the proposed control strategy, droop gain (K) converter's the voltage error into command current for the source of the converter; where converter current tracks as reference current in the steady state relation [159]. The droop control strategy of MG, shares the reference current (I_{ref}) among all converters available in the system without

any central controller. If a SSH fails or isolated from the system, remaining other components sensing decrease DC bus voltage and increase respective output current. The reference power P_{ref} used as input for the community battery controller, the possible reference power can be calculated by the following equation suggested in [160] and [161] expressed bellow;

$$P_{ref} = G(s) \left[V_{ref} - \left(\frac{W_{LP}}{S + W_{LP}} \right) V_{DC} \right] V_{DC} \quad 4-10$$

$$V_{DC}^* = V_{ref} + K \times V_{DC} \quad 4-11$$

Where

- P_{ref} = Reference Power
- $G(s)$ = Transfer function
- W_{LP} = Cutoff frequency
- V_{ref} = Reference voltage
- V_{DC} = DC bus voltage
- V_S = DC source voltage

To avoid or reduce failure in the MG system, proposed designed with some redundancy. A community battery proposed in the MG for backup power which is control by a central controller shown in figure (4-58). The reference DC bus voltage V_{DC}^* of certain DC bus voltage is equal to the reference voltage V_{ref} added with droop gain (K) multiply with input DC current present in equation (4.11)

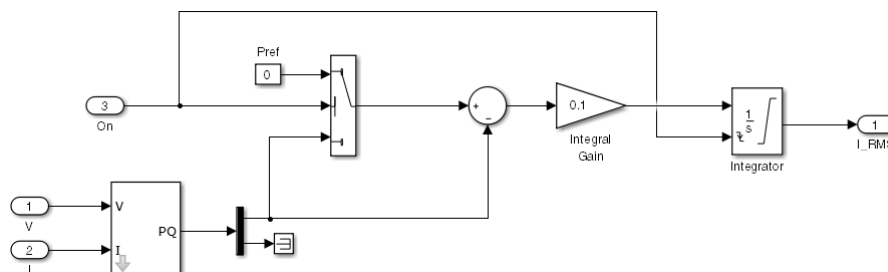


Figure 4-57: community storage controller

Proposed MG embedded with PV major source generated power system, and storage connected with the loads. The proposed converter used in the system is DC - DC bidirectional buck - boost converter, which is operated through the individual control strategy present in figure (4-59a). The converters used in the system operates both buck and boost mode simultaneously. The mode of converter described in graphically represent in figure (4-59b) and the scenarios of conversion strategy deployed in the MG described below:

Senario-1: PV generated current used to charge the battery

Senario-2: Power supplied form the battery to the DC bus in the MG

Senario-3: when Battery is full, the PV generated power directly delivered to the MG

Senario-4: Household loads energy consumed from the DC bus

Senario-5: battery charging from the DC bus of MG

Senario-6: PV generated current delivered to the households' load

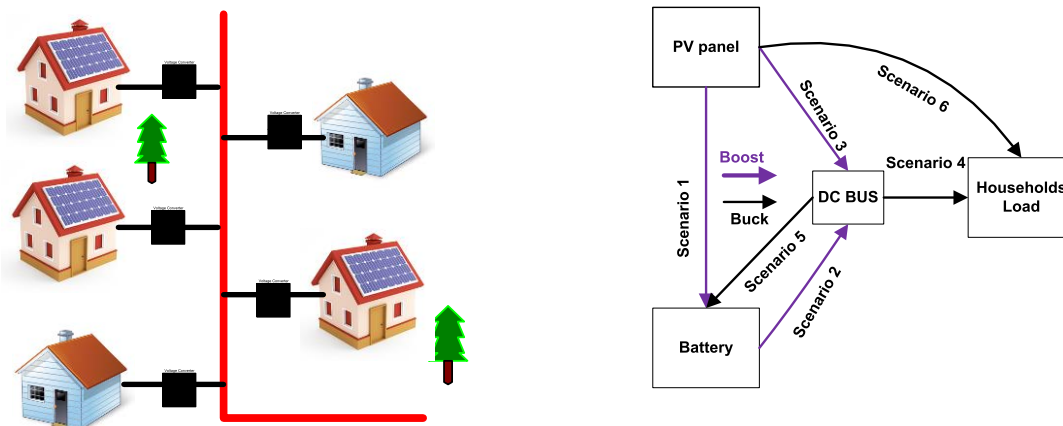


Figure 4-58: (a) multi-tiered MG (left) and (b) converter conversion strategy (right)

4.6 Energy Management System

A smart energy management imposed in the system to control household energy consumption, by adopting droop control strategy and proposed smart energy management system operates reliable and stable performance to ensure battery storage

management and best utilization of PV power. The proposed smart energy management strategy is composed with a several Home Energy Management which is integrated into the MG system. By voltage control reduce the power consumption of the household. The individual SHS adopt HEMS algorithm with control load voltage and DC bus voltage by droop control. Voltage droop control mode of SHS Energy Management shown in the flowchart (4-60), when load power (demand) above the threshold power DC bus set to a minimum standard as 24 V, this mode operate until Load power bellow user defined of home threshold power level.

Power generated by the PV module in each SHS exceeds the load power, the surplus delivered to the DC grid and BHS consumed and stored energy form the DC grid. The proposed energy management of MG present in the flowchart (4-61). If there any fault in the system MG operate standalone mode. The battery state of charge SOC above 95%, battery disconnected from PV module.

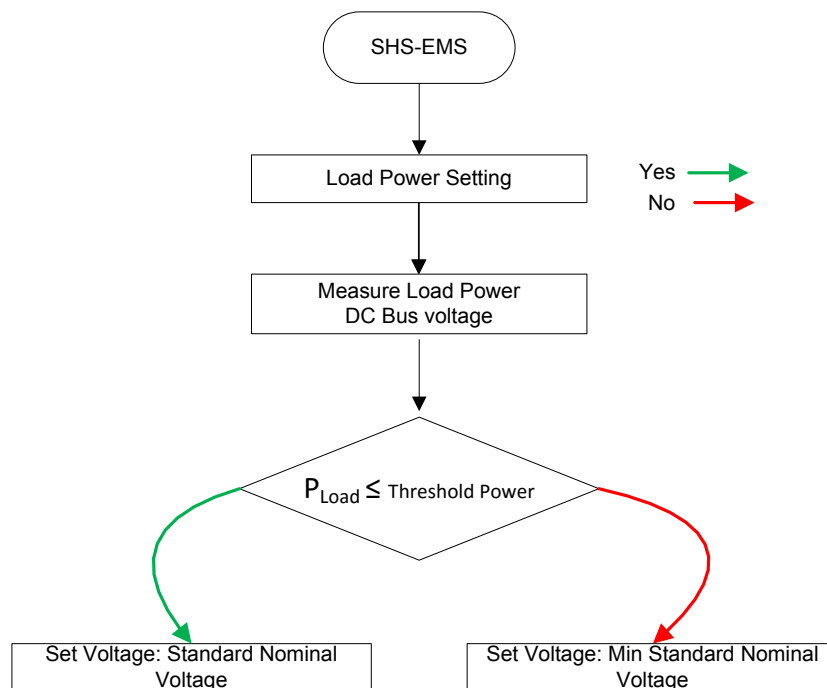


Figure 4-59: Home-Energy Management System

A community battery storage or battery size can be increased in the proposed system to utilize those excess power. If battery power is higher than the load power (demand) and battery SOC $\geq 90\%$, the surplus power delivered to the utility grid.

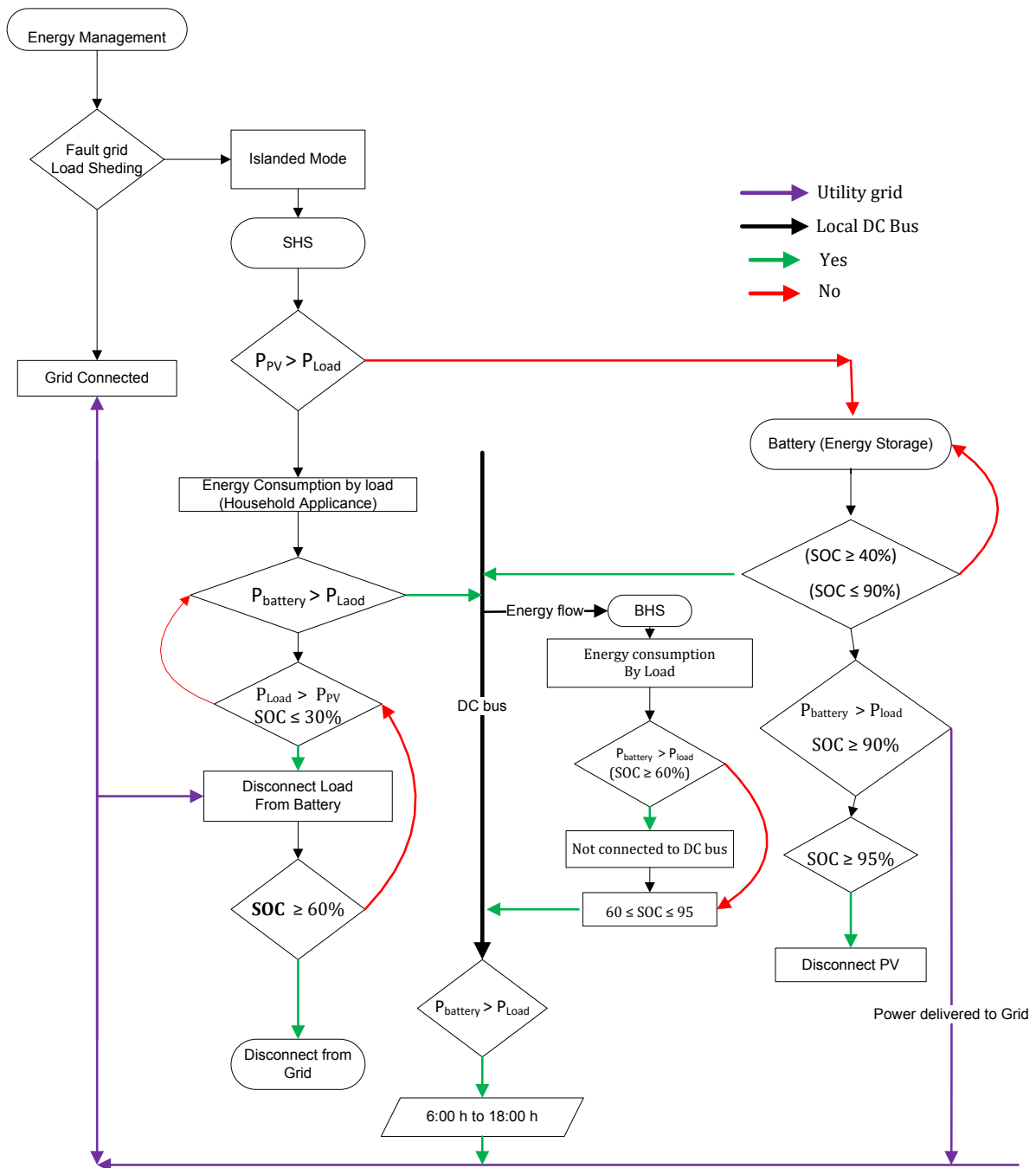


Figure 4-60: Energy Management of MG

Nevertheless, the capacity of battery between ($SOC \geq 40\%$) and ($SOC \leq 90\%$) power supplied to the DC bus, as others SHS and BHS can be consumed by the loads and able to stored energy into the battery simultaneously. The stored energy in the battery at $SOC \geq 90\%$, the MG delivered back to the utility grid. If battery stored surplus energy at $SOC \geq 95\%$, then battery disconnected from PV. When PV generated power is greater than the Load power (demand), PV supplied energy directly consumed by the loads and

stored into the battery. If battery SOC is lower than 30 % and the load power is lower than PV power, load disconnect from the battery. And load connected to the utility grid. As utility grid power penetrated into the MG bus, the energy consumed by the household loads until $SOC \leq 60\%$ of battery capacity. When battery capacity reached 60 % the grid disconnected from the MG. If battery power is greater than load power, the surplus power delivered to the DC bus and household loads able to consume energy instantaneously.

4.6.1 Smart SHS Management System

For efficient and controlled power interface with loads of SHS and grid, entail a smart strategy for energy management. Keeping in mind to maximum utilization of PV as the major and primary source of energy for the MG, smart incorporation of all elements within the SHS and optimum operation requires for an efficient system. The concept of the smart home management system, by controlling each individual SHS including their own consumption along with storage, and share surplus energy to the system and sell back excess to the grid. The idea of SHS-Management System is the strategy to decide when battery need to charge, when to consume, real-time demand response and load management, how much surplus energy share among other SHS and BHS, and how much energy can be sold back to the grid by classified controllable, shiftable, and non-shiftable for building energy management [162]. It supports the SHS consumers to customize their energy demand, shares power among all neighbourhood SHS and BHS and monitors and control own power flow. The consumers can select their preferable source of energy. It can also control devices enabling their demand based on priority conditions. The operation of SHS-MS in various scenarios schemes presented in this as the proposal, which scenarios formation based on some possible combination of various topologies. The SHS-MS operates by a smart control unit within it, and each SHS individually control whether standalone or grid tied.

Senario-1

Loads are connected with national grid along with SHS-MS. Individual storage of SHS used for self-consumption and no fed back to the utility grid. The operation formulated with SHS and utility grid along with ICT (information & communication technology) enabled control and monitored by SHS-MS. The household consuming energy from the reserved (private) storage system and operate as off-grid operation if utility failed. The system might also nosedive, and if SOC level is lower and PV not generates as desires show in figure (4-62).

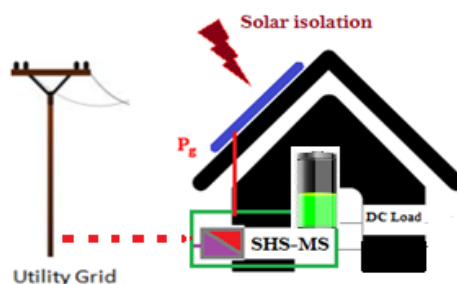


Figure 4-61: System layout for scenario-1, standalone SHS

Scenario-2

SHSs are connected to the centralized storage system (community based storage), where among all SHS in the MG storing their surplus energy into the CBS. The end consumers such as BHS, shop street lights are consuming energy from CBS in the night time. Controlling the centralized CBS is more effective than the private battery system in SHS, it has the ability to store a large amount of energy than individual batteries. Controlling, operation, monitoring, and maintenance can be possible communally by the community based network operator. The total energy charging is very fast and behaves like Electric vehicles storage, and unquestionably requires high power for a very short time within the system. The system turns into more flexible and robust. Due to sharing the PV source energy, if there is the fault in the grid system certain parts of the MG system behave like islanded mode. There is no loss of conversion of energy as generated power is DC, storing in Battery is DC, sharing DC power the power to the loads.

Scenario-3

SHSs connected to the utility grid without CBS, energy storage in the own individual battery, and the surplus energy share among other BHS within the Ad-hoc hum. The scheme proposition allows to utilize the surplus energy rather than wastage. As unpredictable PV and lack of energy, storage opportunity the operation can be challenging with high efficiency. This problem can have solved by the prediction of PV and as accurately, as demand. In economic fact grid power should not supplies to the community based DC MG shown in figure (4-65).

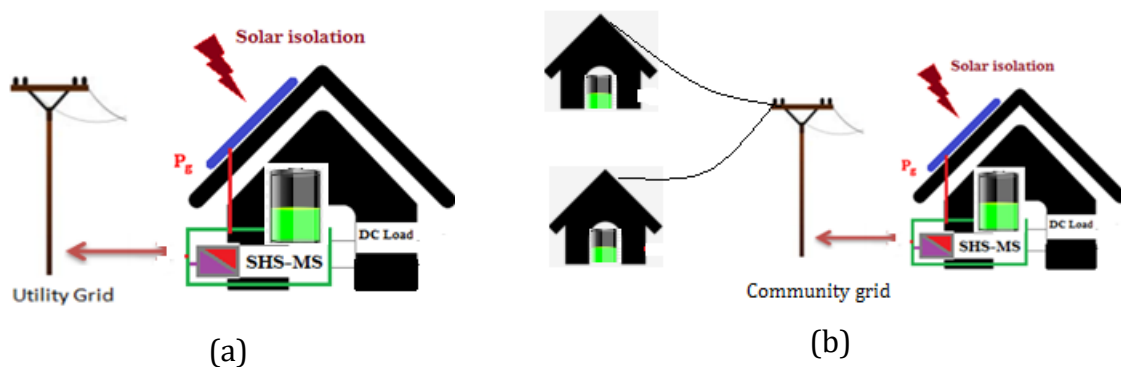


Figure 4-62: System layout for scenario-3; (a) SHS-MS with own battery storage and (b) SHS sharing surplus energy among BHS tied with the DC bus

Scenario-4

SHSs connected both with utility grid and CBS (Community Based Storage), but excess generating DC power store into the CBS along with SHS-MS. The operation mode allows 2 parallel AC and DC grid. DC grid offers reliable network by providing dual voltage network. The excess energy also fed to the utility grid using AC network present in figure (4-65).

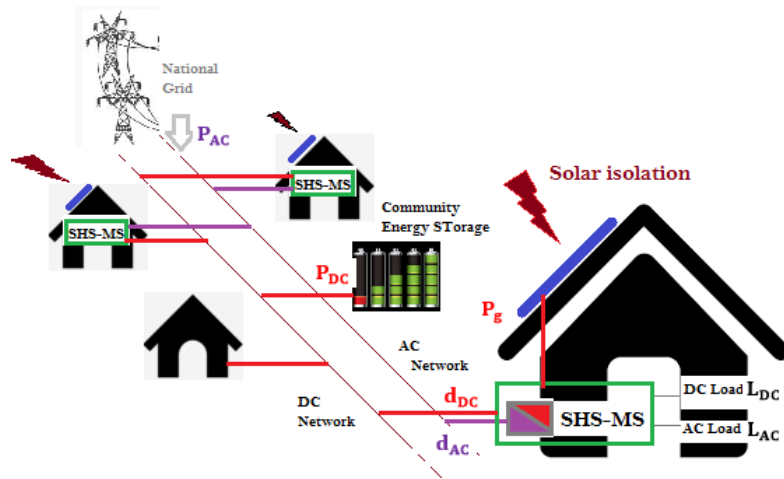


Figure 4-63: Layout of scenario-4; Control SHS-MS tied with both AC and DC Grid

Table 4-4: Comparison of SHS integration

Operation	Technology	Efficiency	Flexibility
Scenario-1	Advance but complex in operation	Low	Low
Scenario-2	Advance & robust but grid can be affected due to numerous inverter during excess energy generation	High	High
Scenario-3	Utility grid affected adversely due to inverter and power quality	Very Low	Limited
Scenario-4	Advance but Complex network Offer AC and DC dual network & Power quality enhanced	High	High degree of flexibility

Summary

The components of the proposed MG systems models attained from theoretical and mathematical equation implemented in the MATLAB/SIMULINK environment. The analysis of power generation from PV panel which depends on real solar insolation and ambient temperature of the proposed location. As the solar irradiation of proposed location fluctuates the temperature also varies conferring to the solar irradiation, cell temperature of PV module effects by the equation ($T_C = T_a + 0.03 \times G_a$). This cell temperature equation assimilated with the PV empirical equation embedded in SIMULINK based model and simulation gave the actual output of PV array. In order to maximum solar efficiency, the maximum power point of PV array tracked by the MPPT tracker strategy and model implemented in SIMULINK to analyzed optimal power generation from PV module. In the system, PV is the major source of energy which is variable and by deployed storage to utilize the best use of an intermittent source of energy. In the SHS, and Standalone PV system suggested charge controller strategy and charge controller model to charged battery and controlled. An extensive investigation of each individual MG components model and configured by SIMULINK based simulation in MATLAB. The dynamic behaviour of MG distinguished the suitable configuration and design can be deployed in the proposed system. The controller operates within the system to maintain constant DC bus voltage to perform the stable system. The batteries used in the SHSs, charged by the PV current and discharge into the loads (households' appliance within the system). Batteries charged by the PV current that should not be higher than 10 % of the battery capacity. Each SHS and BHS composed with 60 Ah capacity batteries that charged with maximum 4 A current that controlled by the charge controller. In the proposed, there are two different types of SHS deployed as Large size SHS charging with 5.99 A and regular size SHS charging with maximum 4 A. If battery charging with the high current; electrolyte of battery lost promptly through the gassing, and PV cell configuration may be damaged as well. The MG design and configure with 12 V system, batteries charged by constant 12 V and no more than 3.99 A and 5.99 A current which generated from 45 WP and 65 WP PV Array. The PV generated current 3.99 A and 5.99 that well-suited for 60 Ah batteries in the regular size and large size SHS. These SHS consumed energy and charged the battery by their own generated PV module, the excess

energy measured by battery capacity ($\text{SOC} \geq 60\%$) delivered to the DC bus of MG. Additionally, the surplus SHS generated power determined by the battery state of charge $\text{SOC} \geq 90\%$, supplied to a utility grid. However, the SOC of SHS at 95% disconnect the battery from PV module.

Country like Bangladesh the one of the sunniest part in the world, where the most preferred renewable source of energy is PV, due to easy installation, almost maintenance free system that incorporates with others SHS, the growth of PV increasing almost 8% in every year. With an enormous potential of PV and local biomass resources produces power which compromises the lossless system. The SHSs consists of a battery when they produce surplus energy sharing among all participants within the system. A smart control strategy for operation, droop voltage control in the MG and droop current control proposed for the SHSs load and demand management. Battery storage performs in the system to increases the dependability on PV and individual SHS control improves the total network stability. The MG system design and modelling only by PV and grid connected offers sharing energy that produces by the PV, and surplus energy sells back to the grid. Although the grid also has the ability to support the MG, but the proposed system only allows to sharing PV power, and each individual system has the aptitude to control the load operation to match PV generation and demand management by smart home management strategy.

Chapter 5

Planning, Sizing, and Optimization of Microgrid

Introduction

Sufficient energy is the fundamental and essential obligation for economic development and social improvement. In Bangladesh, kerosene is the major fuel for lighting and cooking, 90 % to 92 % of energy consumed for lighting in the evening hour fuelled by kerosene and rest of energy comes from PV and utility grid. The high price of kerosene, expensive infrastructure of main grid, and generation and supply of electrical power lagging behind the demand of electricity in Bangladesh; causes an average 6h-8h interruptible load shedding per day. The daily base load in remote and peri-urban areas in Bangladesh reasonably low that sufficiently supplied by local available renewable resources such as solar energy and low scale battery. Demand and peak load in the rural areas in Bangladesh for lighting during the evening. The battery in the typical PV system, used for backup power and best utilization of PV power. To meet the base load and peak load, PV generated power directly supplied to the load in the daylight and evening load meets by the battery stored surplus energy. A typical village in Bangladesh consumes peak load into range 4 to 20 kW and energy consumption about 100 to 300 kWh per day. Progressively growth in electrical demand of such remote areas not yet connected to the national grid, and the energy access in the country like achieved by decentralized energy generation such as standalone PV system, and other renewable energy integration. The opportunity of renewable sources access into the system and well complementary of system configuration analysis, sizing and optimization described throughout in this chapter.

According to [163] Bangladesh is the largest country by densely populated with 158.5 million by 2015, where about 80 % of the population live in rural areas but only 49 % of rural population partially electrified. A great potential of solar and biomass resources meets up their demand without the main grid, even though the surplus energy supplies to the grid. In order to rural electrification, a hybrid off grid system integrated with decentralized energy renewable source is the best solution. The proposed site situated in Bangladesh, where the enough solar potential and biomass opportunity can be progressively utilization in the system. The major sources of energy country like Bangladesh play an important role in planning MG, where average solar insolation to 4.3 to 6.5 kWh/m² and average sunlight and 10.2 h correspondingly a huge amount of

biomass resources available including rice husk, jute stick, animal manure, sugarcane, and tree branches and leaves. About 70 % of the population in Bangladesh still directly or indirectly depending on biomass energy [164]; for cooking about 95 % of the population rely on biomass in rural areas and almost 99 % of people used dry cow dung, jute stick, tree branches and leaves as biomass. In addition, 70 % of people consumes kerosene for lighting purposes [165]. In this chapter focus on optical planning, saying and operation of each component of the proposed MG for ophthalmic design and the degree renewable faction that minimize the dependencies on the utility grid.

5.1 DERs MG Configuration and Planning

Homer Pro dedicated to evaluating and analysis the technical and economic feasibility of hybrid MG system. By using Homer Pro microgrid Analysis Tool, the physical configuration of renewable integrated energy system design, the capital cost of investment, life-cycle cost, operating and maintenance costs and different types of technical appraisal taken under consideration for the best suitable planning of MG modelling [166]. The optimization of the technical assessment of MG planning done by different constraints such as renewable fraction, the capacity of energy generation and load demand. By simulating energy balance with hourly base and peak electrical demand Homer able to determines the local renewable source generated electricity supplies and the gap or surplus between the demand and supply. Homer pro tools also have the ability to configure the best technical and economic feasible design that utilize the renewable energy with a maximum degree of the fraction. The simulation result optimizes the design and configuration of the system that satisfies the desire technical and economic feasibility. During the simulation, modifying some input in the range of feasible and reliable in order to compare the different scenarios by the sensitivity analysis.

5.1.1 Load Profile

Traditionally the demand in Bangladesh restricted during the evening hours, mostly for lighting. As growth of human life style with socio-economic improvement, the electricity

demand also increasing. The winter load has considered half of the summer load due to absence of ceiling fan not in operation. The households load demand variation considered as 5 % day-to-day random variation. The peak load of the system with 20 household considered as 4.189 kW and daily energy demand about 46.102 kWh winter peak load decreased to 2.08 kW and daily consumption reduced to 20.40 kWh. However, the winter and summer base load shown in figure (5.1).

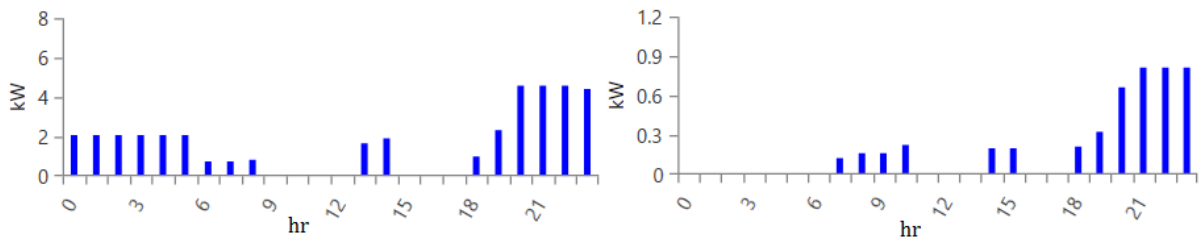


Figure 5-1: Average Daily Load profile (left) summer & winter (right)

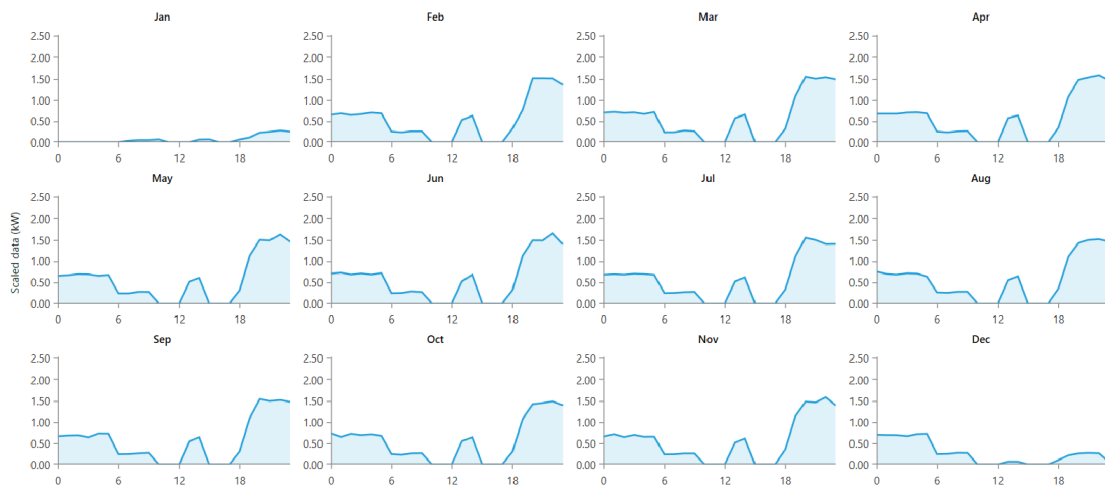


Figure 5-2: Individual 12 months electrical Load Profile

5.1.2 Thermal load

In this chapter, the thermal load assumed only 5 % of the day-to-day random variation of the primary load present in figure (5-3). The scaled annual average thermal load consumption assumes around 12 kWh per day. The scaled peak load is 2.1 kW, with the capacity factor of 25 % to 35 % considered. The average peak load around 0.41 kW of thermal energy considered for the cold storage. The average thermal energy consumes around about 9.79 kWh during winter and 15.7 kWh per day thermal load consumption

during the summer period. During summer the cold storage operates 18:00 h and 10:00 h in winter and consumes both thermal and electrical energy, the peak hour considers 9:00 h to 18:00 h and 11:00 h to 14:00 h summer and winter season respectively present in figure (5.3) and (5.4). The idea of adding thermal load in this chapter is to examine the impact of excess energy feeding thermal load. The figure (5-3) represents the thermal load profile that converted to chilled air or chilled liquid by absorption chiller, and the thermal energy generates by CHP that operates through micro turbine and boiler. In the system, cold storage load demand variation considered as 5 % of day-to-day random variation and load factor considered 0.2.

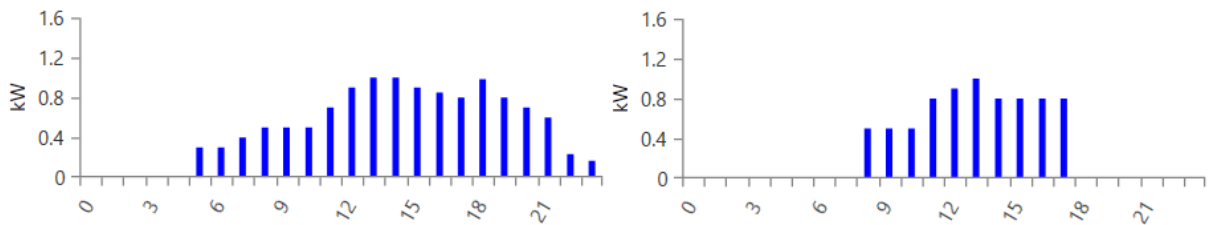


Figure 5-3: Daily Load Profile of Thermal Load Summer (left) & winter (right)

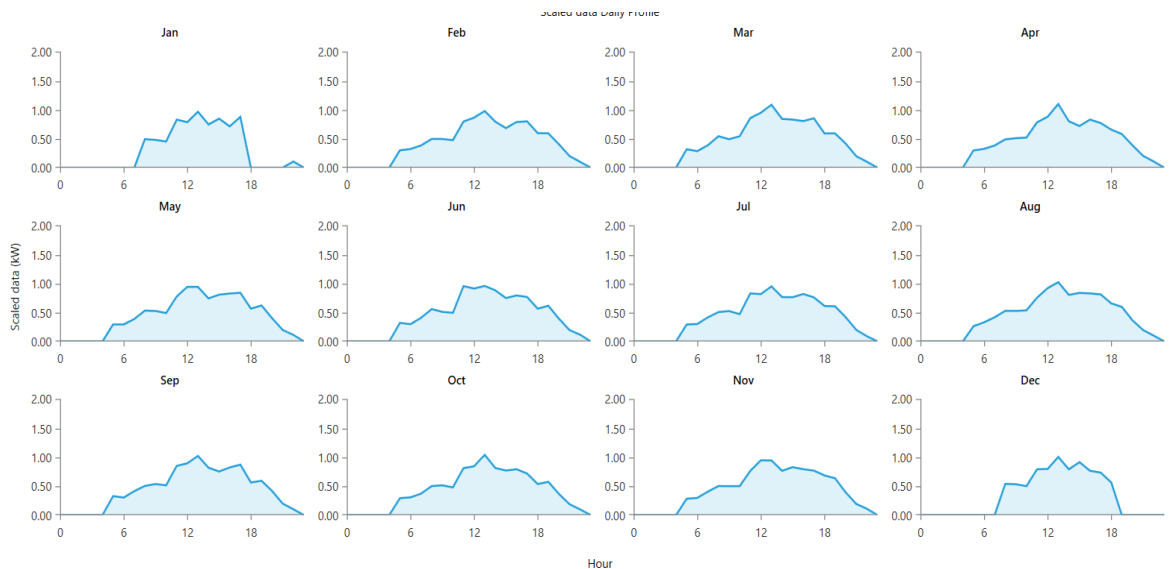


Figure 5-4: Individual 12 months thermal Load Profile

5.1.3 Community based cold storage

The community based cold storage placed in system, where cold storage connected in the DC bus or AC bus. The different scenario based MG configuration, load of cold storage shown in figure (5-5). With the peak load 0.8 kW, and peak energy consumption 6 kWh/day over summer seasons. Cold storage consumption of thermal energy and electricity from around 5:00 h to 24:00h during summer and 8:00 h to 18:00 h during winter season.

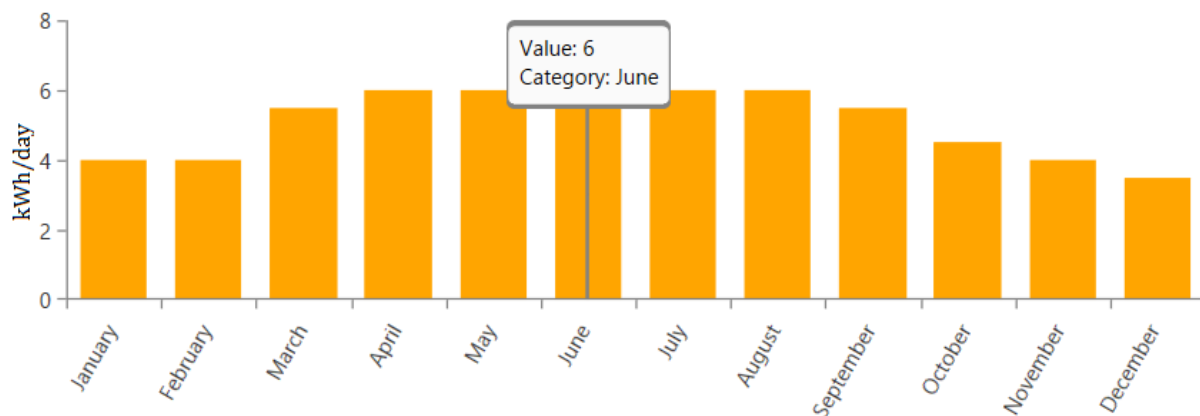


Figure 5-5: Average electric load profile of Cold Storage

5.1.4 Energy Sources

The proposed system positioned in Gopalganj, Bangladesh, 23.2 °N, 89.8° E. Due to low wind speed (average 2.55 m/s annual wind speed), the site does not have enough and sufficient wind potential to produce optimal power for the system. The flat land location does have any micro-hydro potential but enough biomass and PV is ready to use for the optimal and efficient result for planning MG.

5.1.4.1 PV Module

For the proposed MG planning and configuration, three sources took under consideration solar PV, biomass, and main grid. The proposed site does not have micro-hydro and wind potential for ready to use. There is some limitation to deploy wind energy due to less

wind speed and experiences. Nevertheless, solar PV and Biomass generated system have the potential to generate electricity with 80 % to 90 % degree of the renewable fraction. Solar availability in the suggested location obtained from NASA surface metrology available in Homer tool software. The annual average solar radiation for the proposed location is 4.68 kWh/m² shown in figure (5-6). Installation on the rooftop of the traditional houses in the proposed location where design and planning for the position of PV module surface cause partial shade and according to [167] the performance factor of photovoltaic significantly affecting on the shade factor of significantly affected.

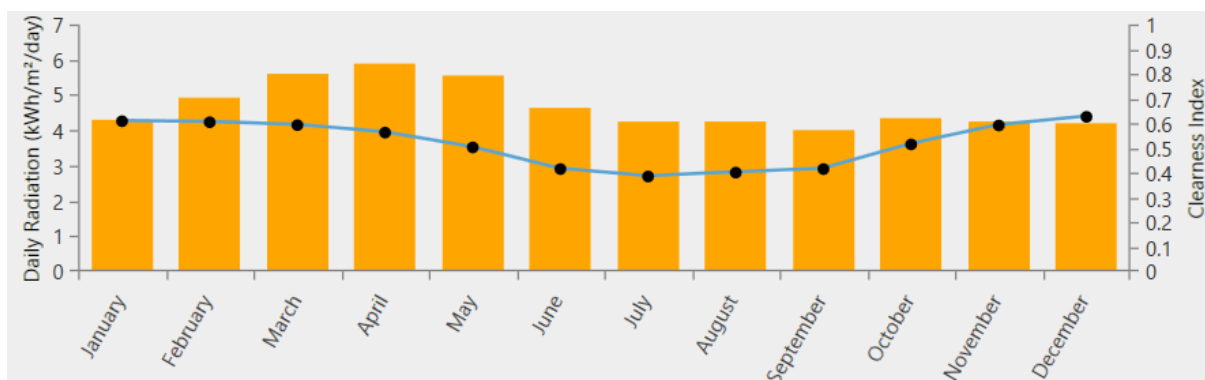


Figure 5-6: Monthly based Daily Average Solar Irradiation (kWh/m²/day)

PV module has selected for the system as proposed scheme, where 45 WP to 65WP peak SHS will be using these PV modules on their rooftop. The suggested Kyocera 65T Multicrystal PV module which has high efficiency in output and reduction of its efficiency in performance only 6.1 % of irradiance decrease 1000 W/m² to 200 W/m² [Annex-1]. In the small module has the better performance than large size module as the partial shading increases. The shading increases the module with a small size still, has better performance than the bigger one at the same percentage of shading. With increased shading of PV module from 25 % to 50 % and 75 %, the voltage and currents drop decreases. In practical experience, at 25 % shading Kyocera and Solara module voltage drops 19 % and 20 %; at 50 % shading voltage drops 20 % and 35 %; 26 % and 37 % [168]. Hence, Kyocera Module is the well-suited PV module for planning. The following at bellow explained PV module suggested for planning MG.

Aging factor influence PV module performance for each and specific module, the PV module performance reduced about 85 % in 20 years. The reduction of performance

reduction about 0.99 % of such PV module per year. The empirical formula expressed the aging factor determined by the following equation in (5-1), that represents the PV module configuration for optimal MG design.

Table 5-1: PV Module Configuration and Sizing

PV Module	Kyocera
Module Consideration	
Case-1 size: Optimal Size Consideration	3 kW to 5 kW (0.5 kW in every step)
Case -2 size: Optimal Size Consideration	3 kW to 8 kW (0.5 kW in every step)
Life time [year]	20
Derating factor [%]	80
Temperature effects on Power [% / °C]	-0.5
Nominal Operating cell temp [°C]	47
Efficiency at STC [%]	13
Ground Reflection [%]	20
Panel Slope	22.98
Tracking System	No tracking (partial shading)

$$\frac{1}{20} \sum_{i=0}^{19} 0.99^i = \frac{1}{20} \times \frac{0.99^{20} - 1}{0.99 - 1} = 0.91 \quad 5-1$$

5.1.4.2 Biomass

In Bangladesh, around 49 % of the rural population connected to the grid, whereas 70 % population are living in the rural and remote areas, where only about 25 % people connected within the grid system [169]. The noble “Vision-2021” of Bangladesh government have set to the electrifying entire country by 2020, and according to the vision local resources especially DERs utilization would be the solution for energy access in Bangladesh. At present, residual waste and another form of biomass waste such as kitchen waste, firewood leafs, and agricultural waste destined as bio-energy. The proposed system located where, the biomass resources are collected from about 200 castles, over 500 goats, poultry farm with over 5000 chickens and ducks produce biomass waste, and agricultural waste like rice husk, local tree branches, and leafs estimation has already been described in chapter-3 (in section 3.2.3.1).

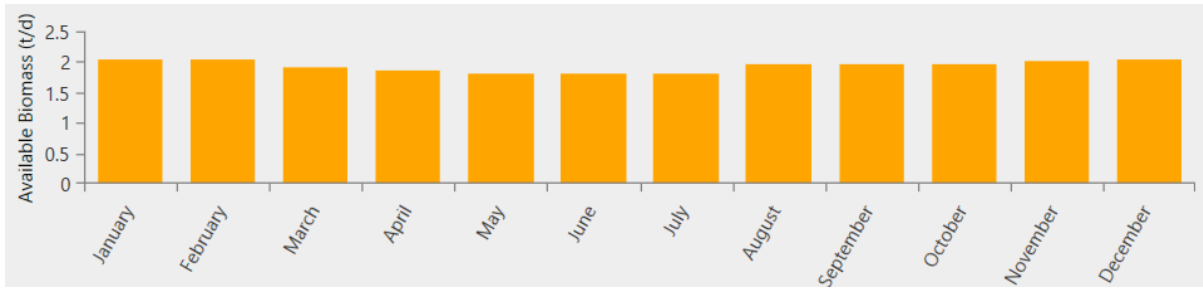


Figure 5-7: Available Average monthly Biomass (tons/day)

5.1.5 Battery

The system suggested with 12 V batteries with maximum capacity 83.4 Ah from Homer tool software 1 kWh generic Lead Acid battery considered for the MG model. The proposed power system scheme configured with a number of battery range from 10 to 20 strings connected in parallel, the step of change of battery taken under consideration 2 for optimal design configuration and well suited for complying the storage backup. The table at bellow explains battery number and size suggested for planning MG. The proposed MG systems consist of integrated SHS; those are connected in parallel in the system. The total battery string is coupled separately to the individual SHS systems, are also connected in parallel. The capacity of batteries optimizes by the Homer simulation and the configuration.

Table 5-2: Battery Configuration for MG System

Battery	Generic Lead Acid Battery
Nominal Voltage [V]	12.0
Maximum Capacity [Ah]	83.4/ each battery
Round trip Ratio [%]	80
Battery per string	1
Initial SOC [%]	80
Minimum SOC [%]	30
Optimal size Consideration	4 to 15 String (in parallel)
Nominal capacity	800 Ah-1200Ah
Minimum Battery life (y)	8

5.1.6 Converter

The system configured with DC –AC or AC - DC bus. PV generates DC electricity, whereas MT generates AC electricity. The residual loads connected within DC bus, and Cold storage connected in AC bus. Converter is required to transform both AC electricity into DC and vice versa. The converter considered along with rectifier and inverter. The system also configured with main grid where surplus electricity sells back to the grid. Assumptions considering for grid connected system bellow:

- Batteries charging prohibit from grid
- Electricity sell form battery
- Prohibit grid sells from battery
- Prohibit any battery discharging
- Only surplus instantaneous electricity sell back to the grid

5.2 MG configuration and Modelling Assumptions

The optimal design MG, energy supplies from the DERS sources, and assuming 80 % to 100 % from PV and Biomass. The biomass fuelled micro turbine also considered in the configured optimal MG design. The system configured along with 20 households DC loads, which consumed 37.5 kWh per day with 4.83 kW peak demand in the summer season and comparatively low in winter consumption about 22.6 kWh per day with 0.814 kW peak. Energy access and electrifying rural areas, MG and power system configured with several assumptions taken under consideration for best suitable configuration. Planning and configuration of MG factors assumptions bellow: the best renewable resources and size

- The capacity of source of electricity
- The cost of modules used in the system
- Fuel cost and consumption capacity
- The module sizes and their capacity

5.3 Optimum Configuration for Planning of Optimal MG Designs

According to the scheme more reliable and flexible energy system design in order to incorporate local renewable energy resources such as solar, biomass integrated small scale MG that uses a combination of distributed energy generation through SHS pattern within the storage and consumption their energy and surplus share to others who does not have the ability to produce energy. In Bangladesh, Government strongly motivated to encourage designers and planners of MG to incorporate renewable energy into the system.

5.3.1 Simulation and Result Analysis

In this section four scenarios will be discussed according to its optimal result for the suitable planning for the MG. the configuration of the MG that is considered the well suited for technical feasibility, life cycle, and cost of capital of MG for each scenario under consideration. Although in this report author will not discuss cost or any other economic constraints but the optimal design must be complying with suitable for technical appraisal and economic feasible. In addition, the operation and schedules also considered for the best feasibility for the operation, in this context operational strategy and working scheduled is important constraints for optimization. After considered the variable constraints and configuration, the simulation would find out the suitable and feasible optimal design. The Homer Pro tool have the ability to define the optimal MG arrangement, analysis its design and operation which comply the minimum total NPC (Net Present Cost) and desired constraints has assumed [170]. The system has designed and configures with courage, that sharing surplus energy among the community and maximizes utilization of energy a flexible and reliable MG planning for rural electrification. In this context, painstaking renewable sources defined in several factors such as the well-suited source of energy, the capacity of generation and penetration in the system. In the following configuration, PV and Biomass are the major sources of the energy.

5.3.2 PV configured MG without main grid

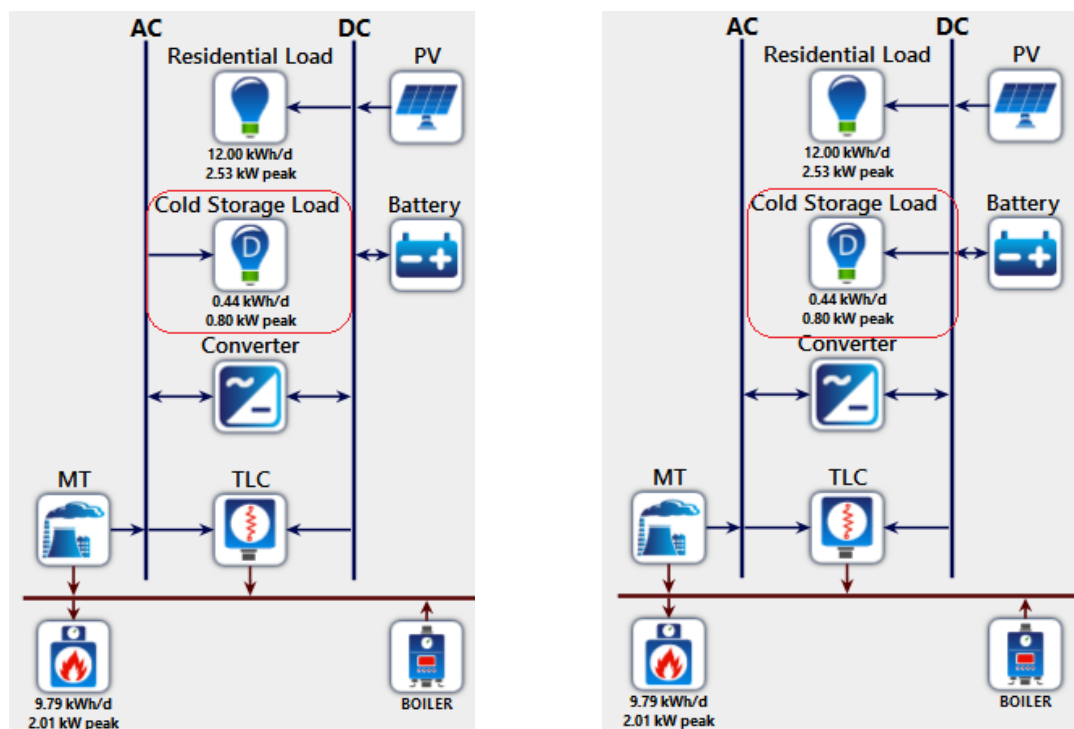


Figure 5-8: Optimal Configuration of MG: cold storage connected in AC bus (case-1) & cold storage connected in DC bus (case-2)

Case-1

The optimal configuration considered with the capacity of 2.1 kW of PV and 1.7 kW MT (CHP) produces 3100 kWh electricity and 4512 kWh electricity by PV and MT respectively. The optimal configuration as present in figure (5.8 case-1), 41 % of electricity produces by PV and 59 % of electricity produces by MT present in figure (5.9). In figure (5-10), the blue spike represents household loads that meet by the electricity that produces with PV modules shows in red spikes. Most of the electricity show in redline consumed by the household loads, and surplus electricity supplies to the cold storage cold. The PV module with capacity factor 16.83 % and produces maximum 1.98 kW, and 8.08 kWh per day. PV modules operate 4370 h, and maximum 67.3 % PV penetration into the system.

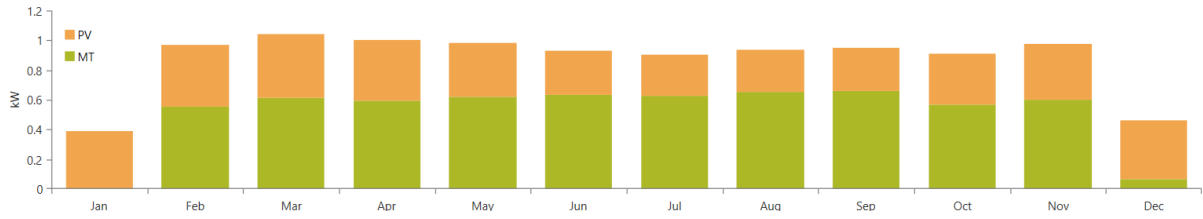


Figure 5-9: Monthly based Average Electricity produces by PV and MT (CHP)

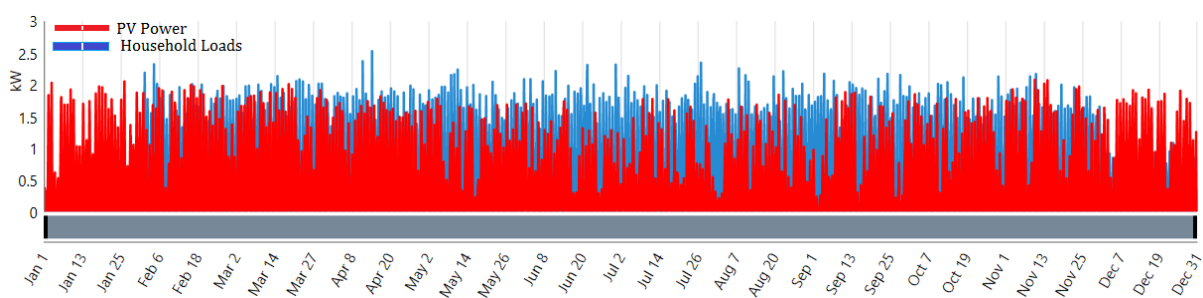


Figure 5-10: Electricity produces by PV and household load

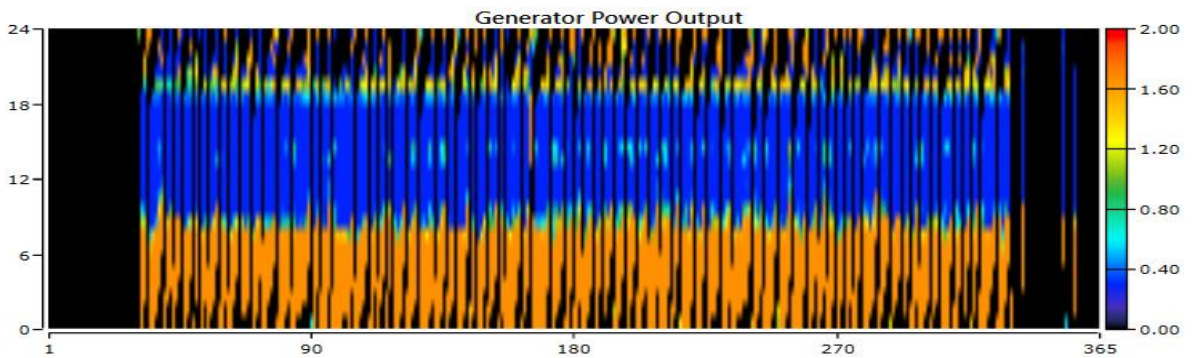


Figure 5-11: MT (CHP) output

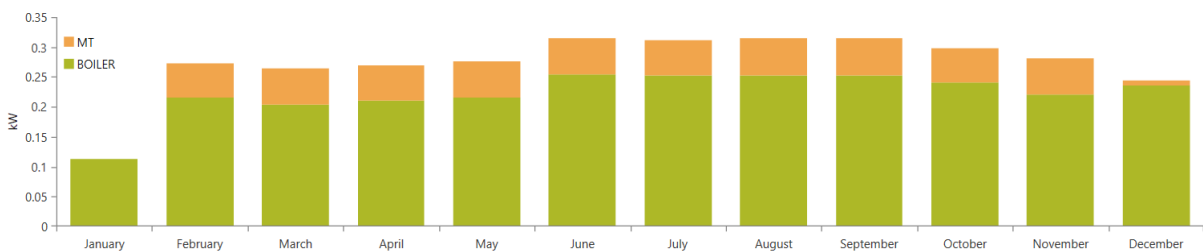


Figure 5-12: Total Thermal Energy produces by MT and Boiler

The system also configured with a combined heat and power MT that produces electricity shows in figure (5-11) and thermal energy in (5-12). In figure (5-12), the khaki color represents thermal energy produced by MT and light olive histogram represents thermal energy procured by the boiler. The combined 4,291 kWh of total thermal energy produces by the boiler and MT. The figure (5-13) present total thermal energy produced by the

boiler shows in spike and black line represent thermal energy produced by the MT (CHP), the grey spikes represents the thermal load.

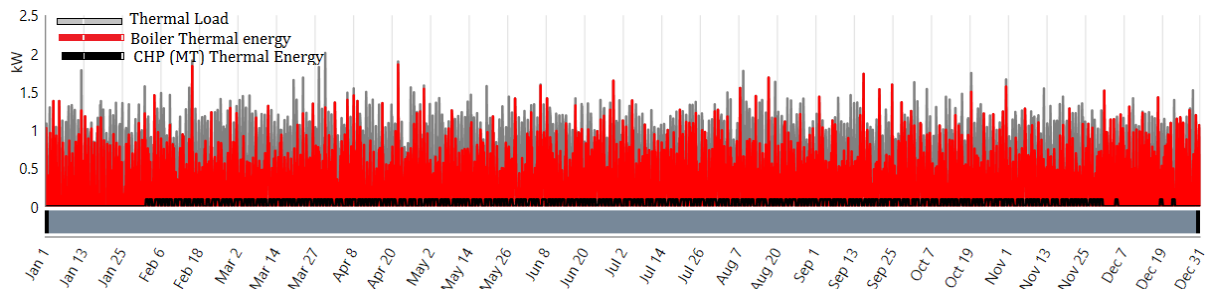


Figure 5-13: Thermal Load vs thermal energy of (MT and boiler)

The MT (CHP) operates 4776 h and generates 4,512 kWh of electricity, 443.1 kWh of thermal energy produces throughout the year, and about 717 kWh (which is 20 % of total thermal energy) the excess amount of thermal energy produces by both MT and boiler over the year. The MT (CHP) with 30.3 % of capacity factor produces 0.94 kW of electricity and 0.09 kW of thermal energy simultaneously. The total 3.93 tons' biogas fuel consumes by the MT (CHP) per year shown in figure (5.14). According to the proposed system, biomass fuelled MT consumes 0.01 tons per day and specific fuel 0.61 kg of fuel consume to produce 1 kWh of electricity. The MT produced electricity with 107.4 % electrical efficiency.

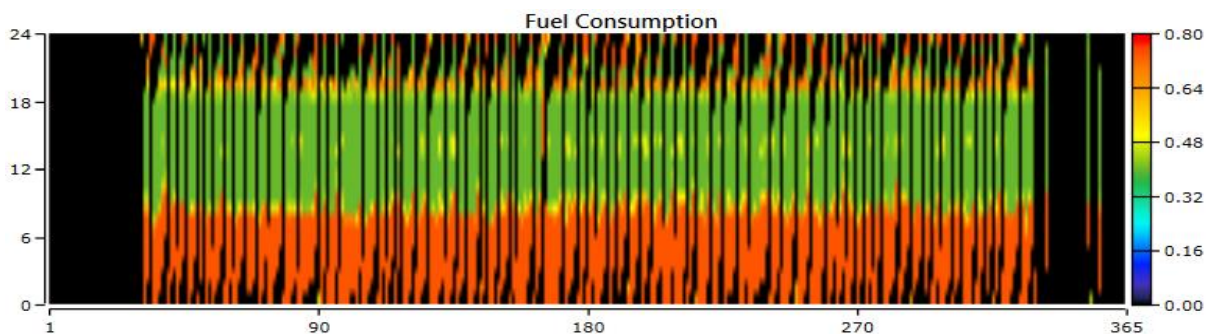


Figure 5-14: Fuel Consumption of CHP

PV mainly generates electricity during daytime and the peak load in the evening, to meets the load energy stores in a battery. In this optimal configuration 15 lead acid battery string connected in parallel, each string considered a lead acid battery with 12 V and nominal capacity 84.4 Ah. The state of charge of the batteries represent in the figure (5-

15), battery autonomy observes about 17 days. During winter, the PV produces surplus electricity and battery state of charge almost 80 % to 90 % shown in figure (5-15) and (5-16), the charging power is higher than discharging power during January and December showed in figure (5.17).

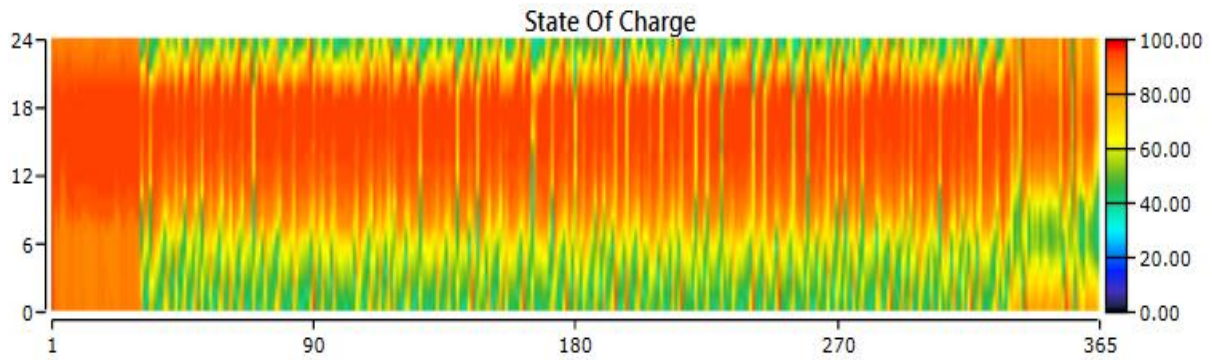


Figure 5-15: Battery State of Charge

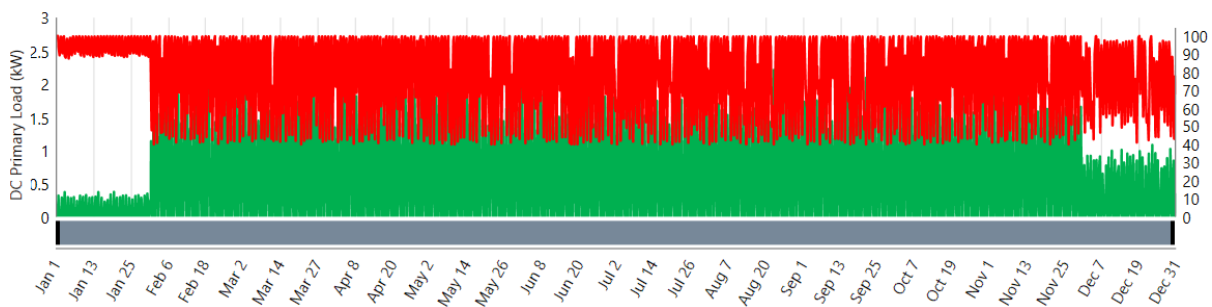


Figure 5-16: Load (green) vs SOC of batteries (red)

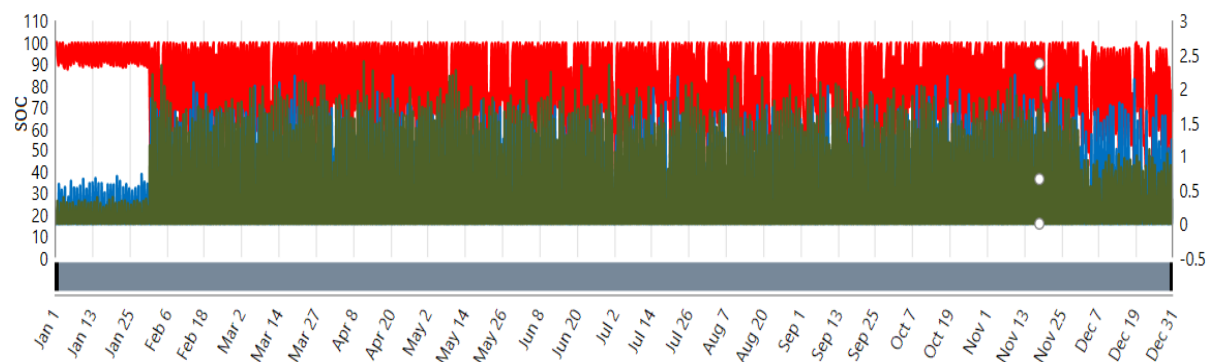


Figure 5-17: Battery Charging Power (blue), discharge power (olive) and SOC (red)

The configuration allows, converts power from MT to loads and PV to loads as well; cold storage positioned in the AC bus and household loads in DC bus. The household loads mainly consumed PV and battery delivered power. The cold storage and household loads

consumptions observed by the converter shown in (5-18). During January, loads are not high as generated by the PV; no power requires, as rectifier converts zero power in that time shown in (5-18 down). Nevertheless, during winter households loads consumes both MT and PV power as convert about 0.01 to 0.02 kW power through inverter shown in figure (5-18 top), whereas in December requires some power from PV and battery to cold storage load shown in figure (5-18 down). The optimal configuration produces about 1903 kWh of excess electricity per year. In figure (5-19) light purple spikes, present the excess electricity produces by the PV and MT, the excess electricity mostly produced by the MT, and red stripe represent the unmet load.

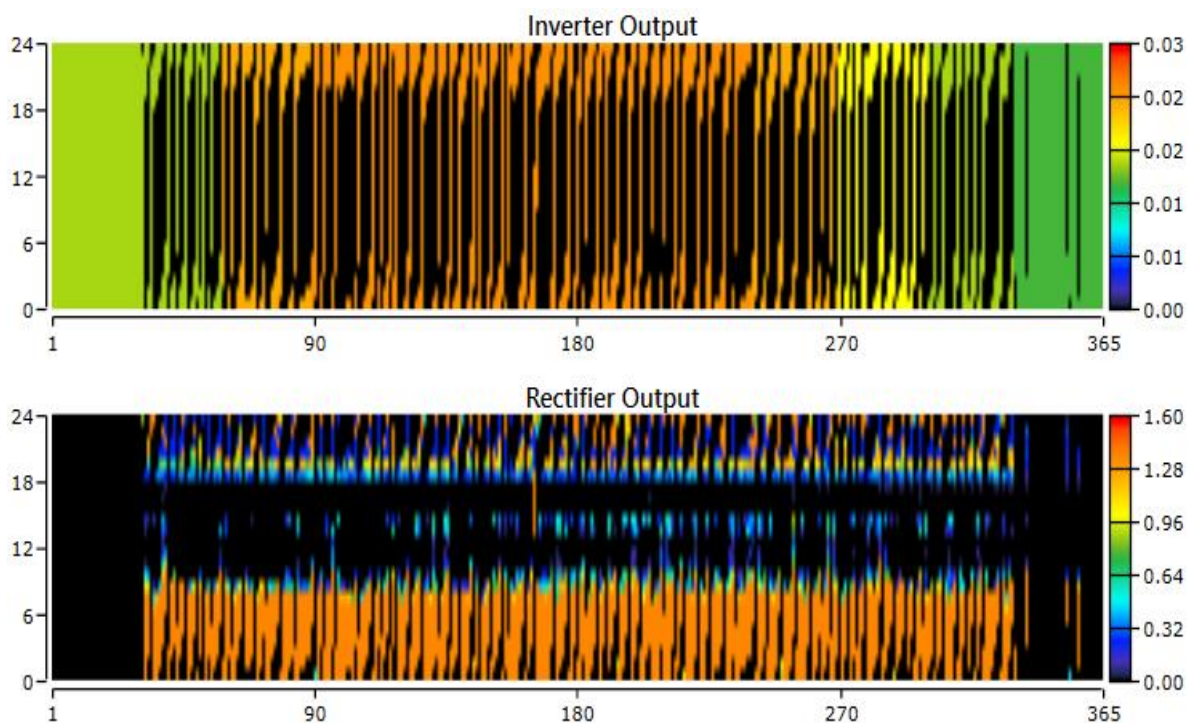


Figure 5-18: Converter output: inverter (top) & rectifier (down)

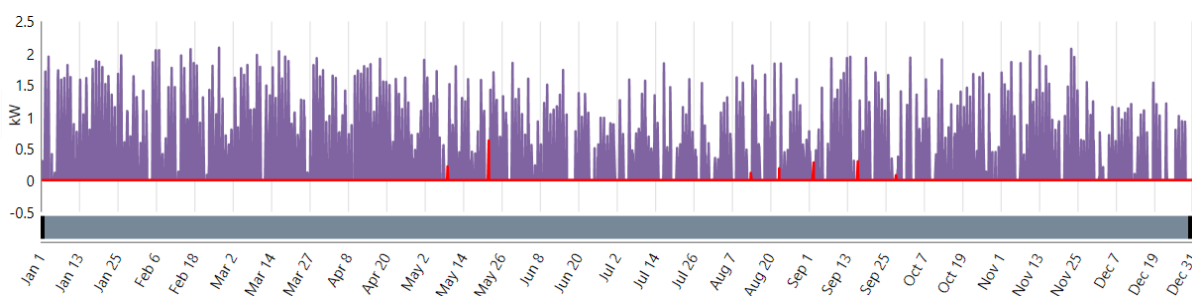


Figure 5-19: Excess Electricity (blue violate) and Unmet load (red)

Case-2

The configured system considered along with the capacity 1.7 kW of PV and 1.8 kW of MT (CHP) shown in figure (5-8 case-2), PV generates 2,507 kWh and MT generates 5,314 kWh of electricity of per year. The PV produces 32.73 % of electricity, and average 7 kWh electricity produces each day. In the system household, loads comprise with the PV generated power shown in figure (5-20), where light olive histogram represent the electricity generates from the MT (CHP) and 67.27 % power generates by the MT.

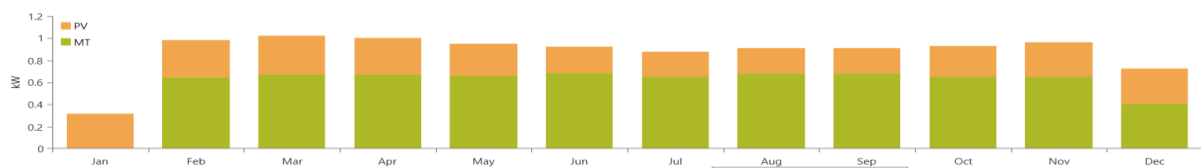


Figure 5-20: Electricity Produces by PV and MT (CHP)

The optimal configuration considered with the capacity of 1.7 kW of PV and 1.8 kW MT (CHP) produces 2,507 kWh electricity and 5,152 kWh electricity by PV and MT respectively. The system allows about 57 % of PV penetration, and the load does not meet by the PV power. Hence, the deficit power needs the household load and cold storage loads supplies from MT (CHP).

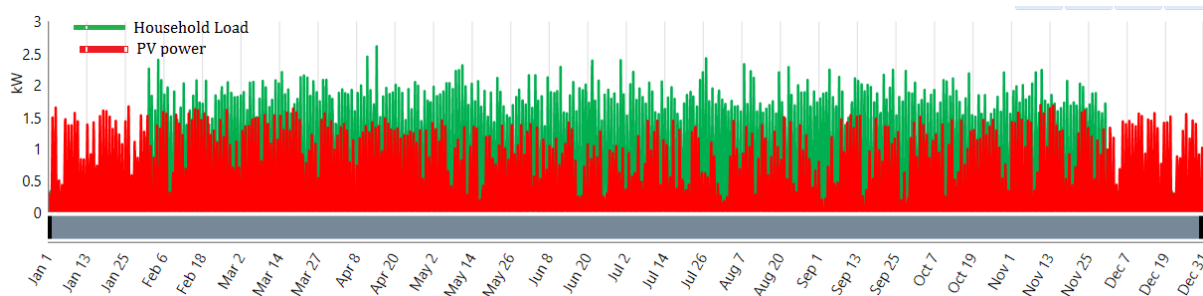


Figure 5-21: Household load vs PV power

The figure (5-21), the green spike represents the household loads and red spike produces by the PV. The MT (CHP) with 99.56 % of electrical efficiency operates 6015 h to produces 5314.3 kWh of electricity and 985 kWh thermal energy simultaneously; the MT drives to produces electricity and thermal energy and consumes 0.01 kg biomass per day and 4.99 tons per year shown in figure (5-22). The specific fuel consumes about 0.66 kg to

produces 1 kWh. The system operates as 84 % of renewable fraction, and mostly daytime renewable fraction generates by the PV and MT is shown in figure (5-23 top), and 100 % of renewable energy consumption as red marks shows in figure (5-23 down)

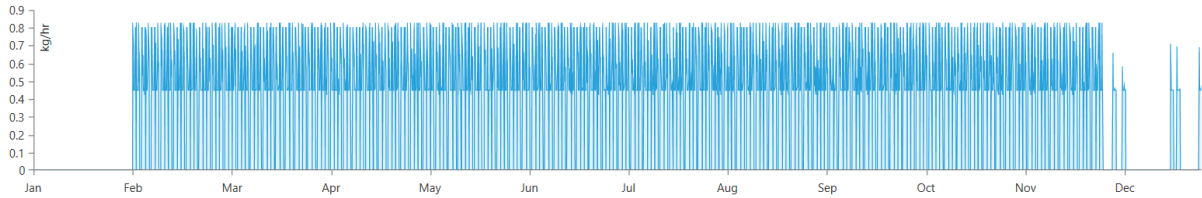


Figure 5-22: Fuel Consumption of MT (CHP)

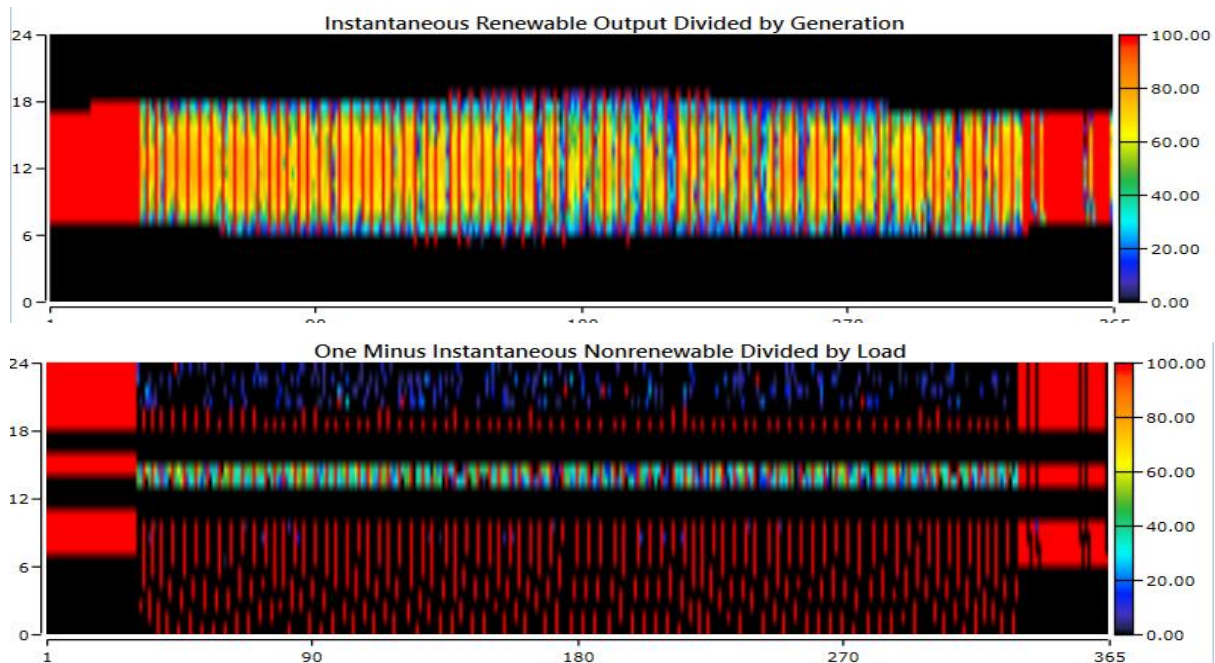


Figure 5-23: renewable output divided by generation (top) & Non-renewable energy divided by the load.

In the system most of the loads positioned in the DC-bus, and the cold storage peak load considers during the daytime; as the battery, size requires small in size to meet the both loads in the system. The system configures with 4 batteries string in the parallel and total capacity of battery 334 Ah. In figure (5-24) present the red line SOC of the batteries over the year, green spikes represent the loads and blue spike discharge power of the battery. The power generated by the MT and PV delivered to the DC-bus, as the only rectifier operates shown in figure (5-25). As MT operated more than to meets the electric power,

some excess electricity produces. The figure (5-26), the light olive colour spike represent excess electricity and red spike represents the unmet load.

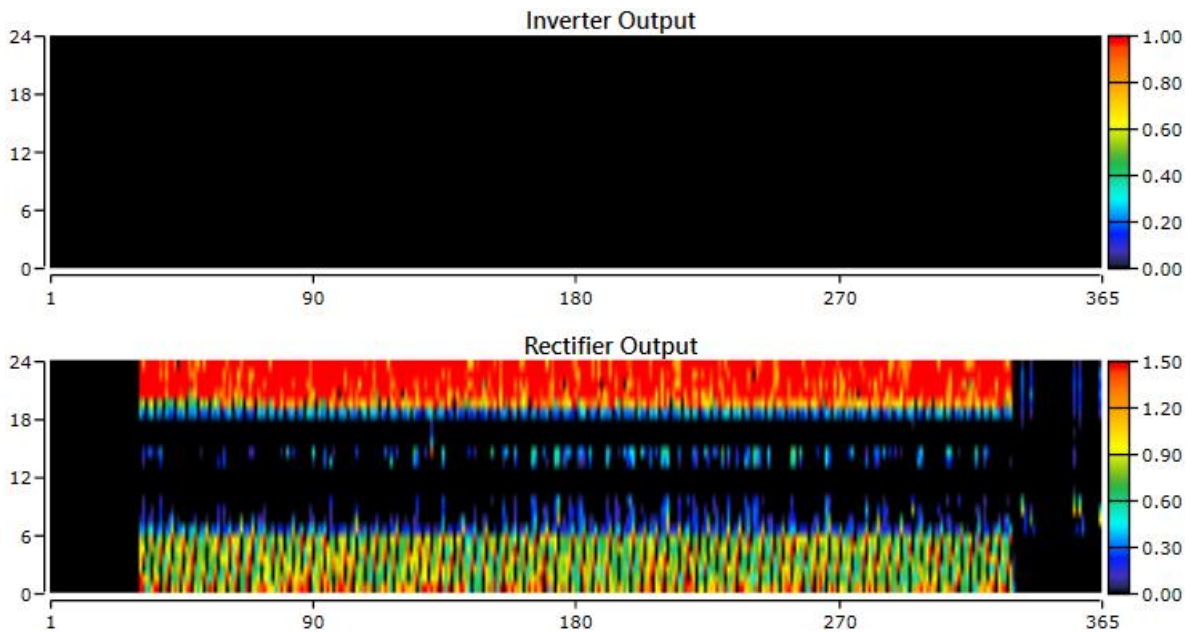


Figure 5-24: Converter; (top) Inverter & (bottom) Rectifier

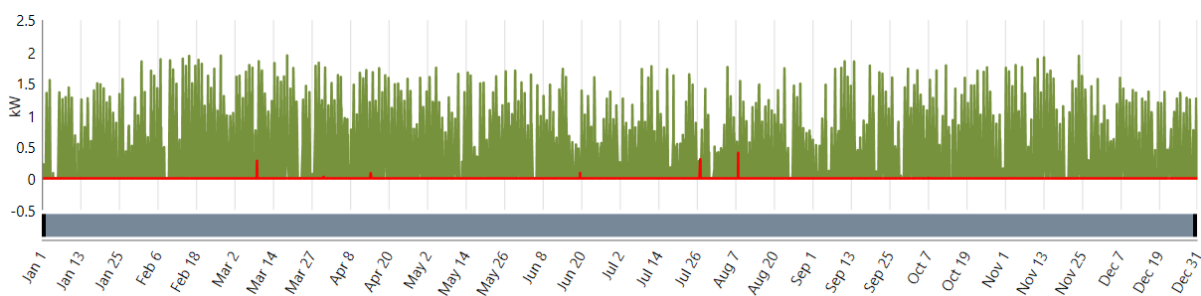


Figure 5-25: Excess Electricity (olive) and Unmet load (red)

5.3.3 PV configured MG without main grid

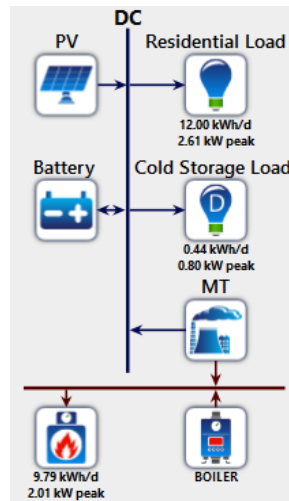


Figure 5-26: DC configured MG

The optimum configuration of DC-MG consists of 0.4 kW of PV, 1.6 kW of MT (CHP), and both loads are connecting to the DC bus shown in figure (5-27). As there is no AC bus system does not require any converter. The system, PV generates 590 kWh per year, which are produces around 12 % of the power that meets the demand. About 13.5 % of PV penetrates in the system, and 1.62 kWh produces per year.

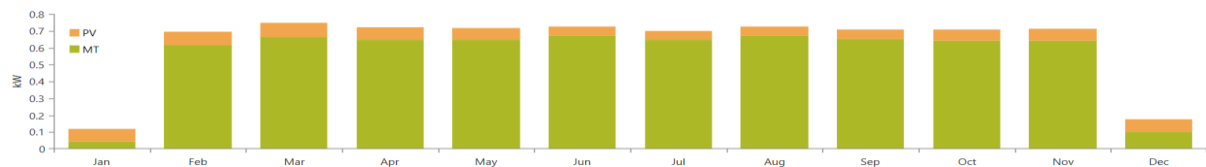


Figure 5-27: Monthly bases Average Electric Power Production

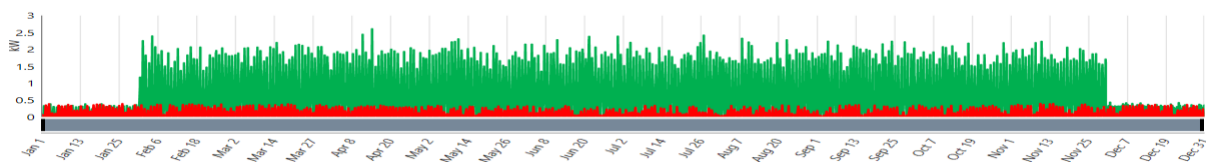


Figure 5-28: Load (green) vs PV Power Generation (red)

As MT (CHP) with 103 % electrical efficiency operates 5,843 h to produces 8,434 kWh of electricity and 850.53 kWh thermal energy. The olive colour and sandy brown shade

histogram presents the electricity produced by MT and PV respectively as shown in figure (5-28). The optimum configures allows PV power which is comparatively lower than the loads, figure (5-30) the green spike represents the load and red represents the PV power.

The MT (CHP) mutually produces thermal energy along with electricity. The CHP with 34.5 % capacity factor produces 851 kWh, which 23.3 % of total thermal energy. Rest of 77.86 % thermal energy produces by the boiler in figure (5-29). Figure (5-30) the blue spike represent thermal load and yellow line represents thermal energy produced by the CHP. The MT produces thermal energy that is not meet to the desired load shown by blue spike, and boiler produced adequate thermal energy present red spike shown in figure (5-31). The red spikes represent sufficient enough thermal energy produced by the Boiler, on the other hand almost diminished blue spike represents thermal energy produced by CHP (MT) shown in figure (5-32).

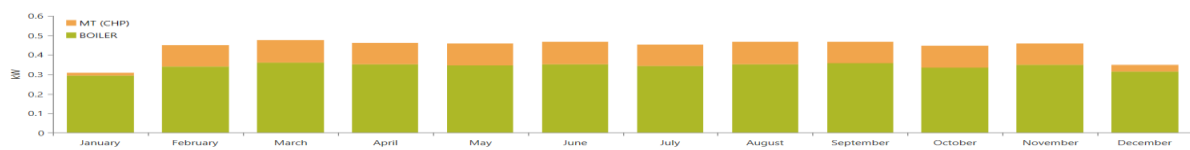


Figure 5-29: Thermal Energy produced by MT (CHP) and Boiler

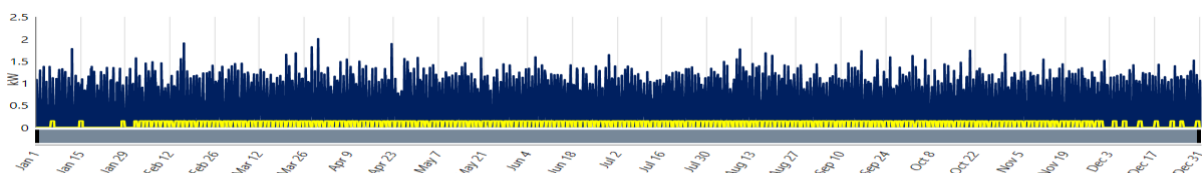


Figure 5-30: Thermal load (blue) vs MT (CHP) produced Thermal Energy (yellow)

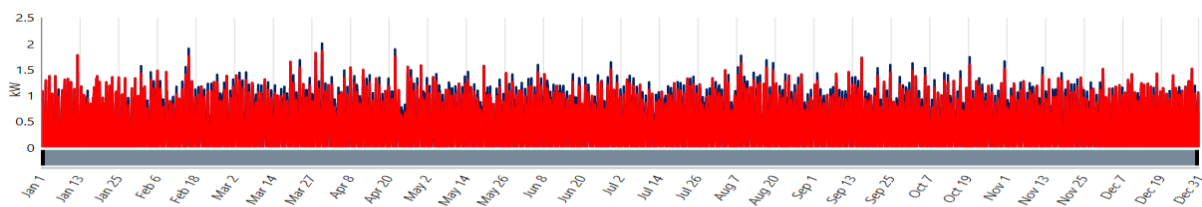


Figure 5-31: Thermal load (blue) vs Boiler produced Thermal Energy (red)

The (MT) CHP consumes 4.4 tons of biomass each year, and the average feedstock about 0.01 tons per day shown in figure (5-33). To meets the peak load power during the

evening, the power supplies from stored batteries. The optimum system configured with 8 parallel string batteries with the total capacity of 667 Ah. In figure (5-34) red shaded spike and (5-35), the histogram represents the battery state of charge. The yellow spike present discharge power, blue pike represent charging power.

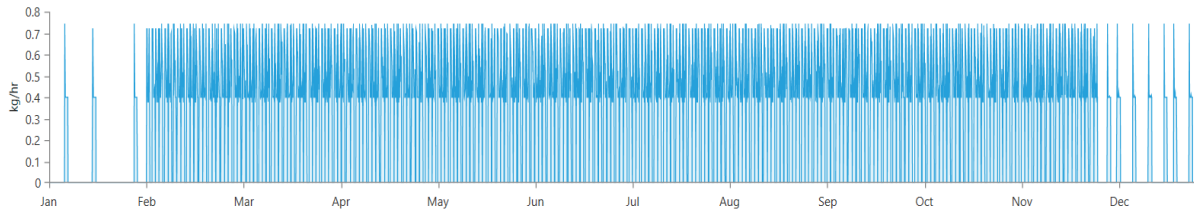


Figure 5-32: Biomass consumption of MT (CHP)

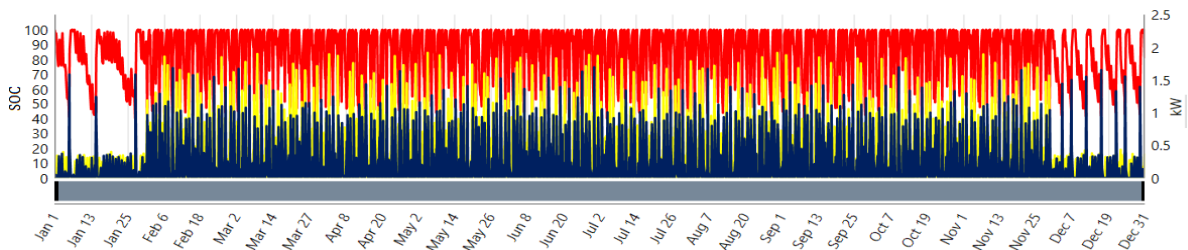


Figure 5-33: Battery Charging (blue), Discharging Power (yellow) vs SOC (red)

The optimal system produces excess electricity and thermal energy 635 kWh and 268 kWh represent in the figure (5-36) and (5-37) respectively. In figure (5-36) the yellow spike represents excess electricity produces by the system and red spike represent the unmet load, figure (5-37) the blue spike represent thermal load and the red line represents the excess thermal load. However, the configured system renewable fraction about 64 % and figure (5-38) represents renewable output divided by the total power generation; the red shade depicts 100 % of renewable penetration.

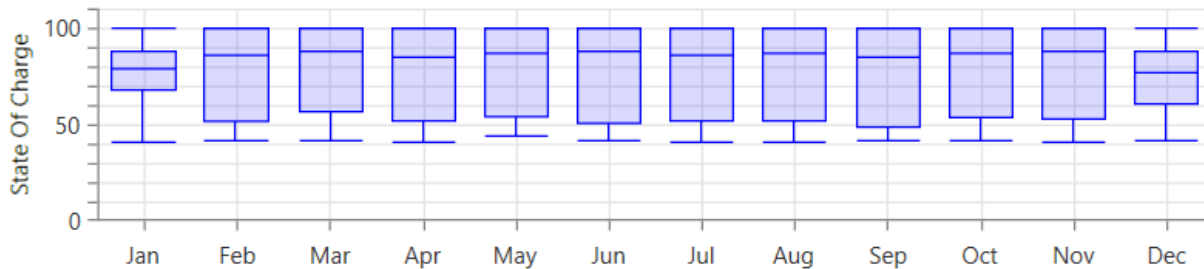


Figure 5-34: State of charge of Battery

Figure (5-39) represents the non-renewable divided by the load; the red shade portrays 100 % of non-renewable energy consumes by the load. Nevertheless, in figure (5-38) exposes close to 100 % of renewable power generates throughout January and December during the daytime. Likewise, figure (5-39) exposes close to 100 % of non-renewable power consumes by the loads for the period of almost every evening and night throughout the whole year.

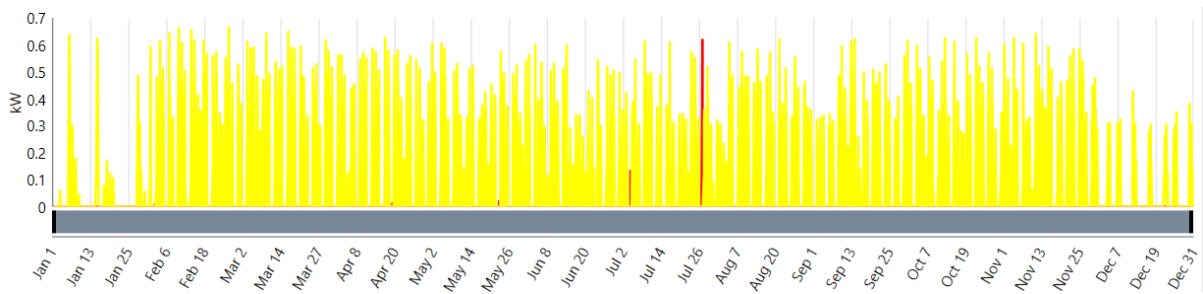


Figure 5-35: Excess Electricity (yellow) and Unmet load (red)

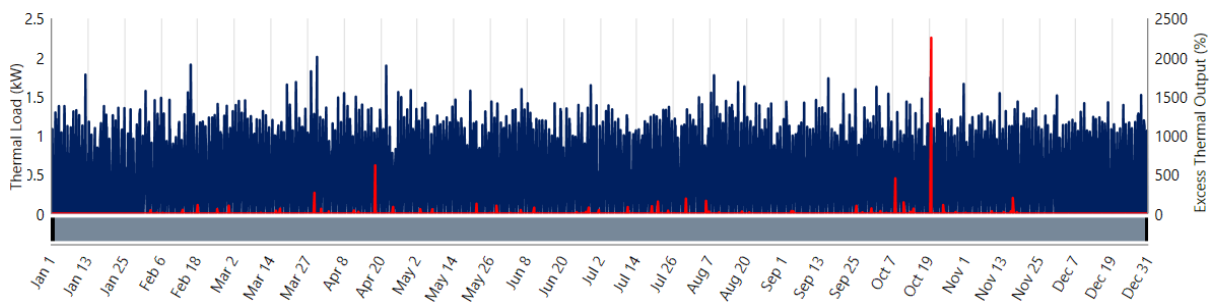


Figure 5-36: Thermal load (blue) vs Excess Thermal Energy (red)

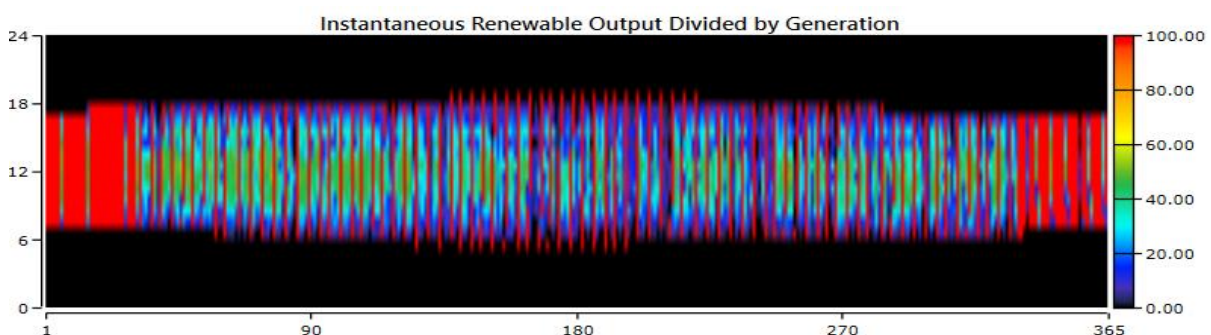


Figure 5-37: Renewable Output divided by total Power Generation

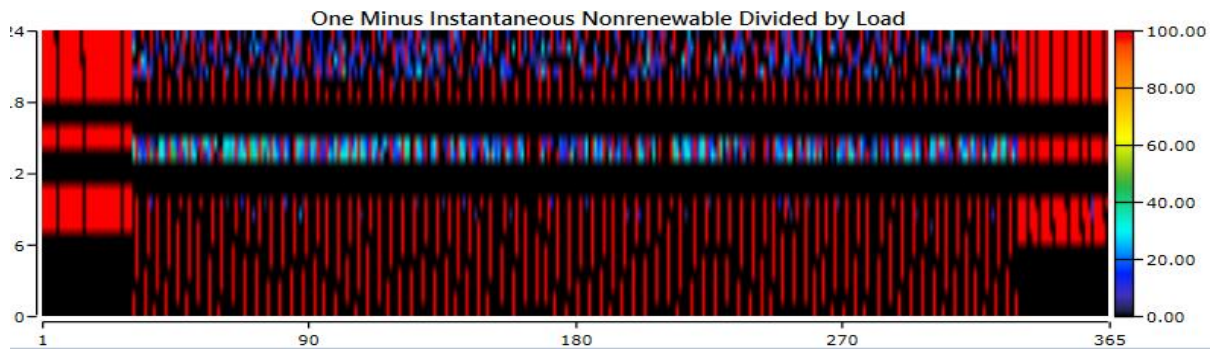


Figure 5-38: Non-renewable output divided by total power load

5.3.4 MG configured with Grid

The configuration consists of PV system, battery, connected in the DC bus and cold storage positioned in either DC bus (case-1) or AC bus (case-2).

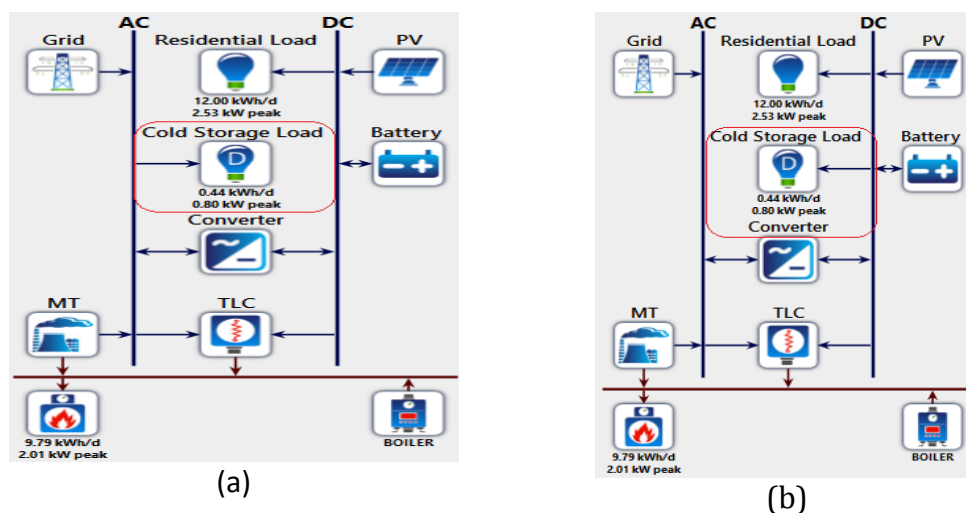


Figure 5-39: Main grid connected configured MG: (left) Cold storage connected in AC bus (case-1) & (b) cold storage connected in DC Bus (case-2)

5.3.4.1 Grid Connected MG: Cold storage connected in AC bus

An external grid connected MG configuration consists of 2.0 kW of PV and 3.0 kW of MT generates in total 11,310 kWh electricity per year shown in figure (5-41); shade brown histogram represent PV and light rust histogram represent MT produced electricity. The PV module with 16.83 % of capacity factor energy produces 8.08 kWh per day. It is clear that there is no electricity required from the main grid to meets the primary load,

whereas the primary DC load requires 4380 kWh per year. The remains surplus electricity sells back to the grid through inverter shown in figure (5-51) and electricity quantity and sell price depicted in the figure (5-62). The optimal system produces 26.08 % electricity from PV and 74 % of electricity from biomass, while the configured system load consumes 43.38 % and rest 55.02 % electricity sell back to the main grid. The maximum renewable penetration in the system about 13,970 that would be about 81.1 % of renewable fraction. There is no excess electricity that wastage in this optimal configuration. In figure (5-42) green line and red line represents, the surplus Electrify Sellback to grid and Unmet Load respectively. The unmet load precisely present in the figure (5-43).

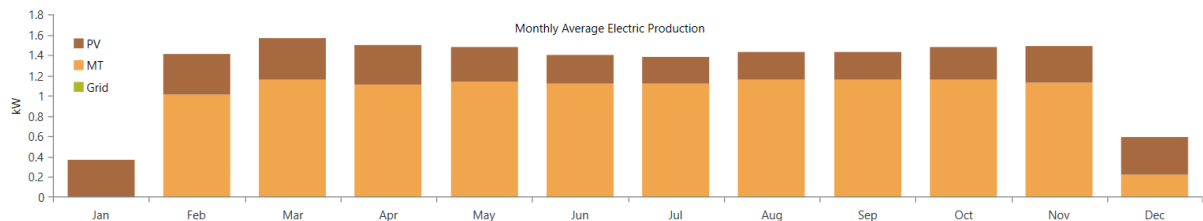


Figure 5-40: Monthly based Average Electricity Generation

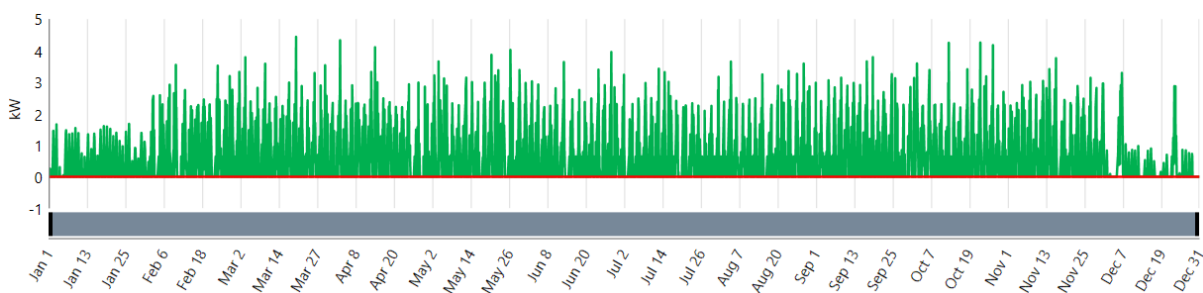


Figure 5-41: Surplus electricity sell to the grid (green) and Unmet Load (red)

Almost Similar fuel consumption compare with the previous scenario, the total thermal energy graphically represents in figure (5-44), whereas MT (CHP) production represents by sandy brown painted histogram and light olive histogram represents boiler generated thermal energy. The month of December and January, the low demand of electricity and thermal energy, MT produces zero 0 kW in January and almost zero kW in the month of December. Throughout the year, 34.69 % and 65.31 % of thermal energy produces from MT and boiler. The cold storage consumes chill air converts from thermal energy from MT (CHP) and boiler generated. In figure (5-45), the green spike presents boiler thermal output and green line shows MT (CHP) thermal energy. Thermal load consumption and the excess thermal output represent in the figure (5-46) and about 385 kWh the excess

thermal energy remains as unused per year. Hence 10.8 % of total generation of thermal energy wastage in a year.

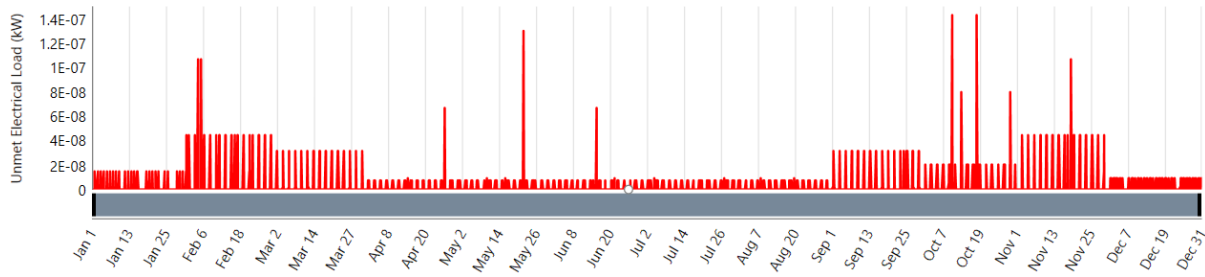


Figure 5-42: Unmet Electrical Load

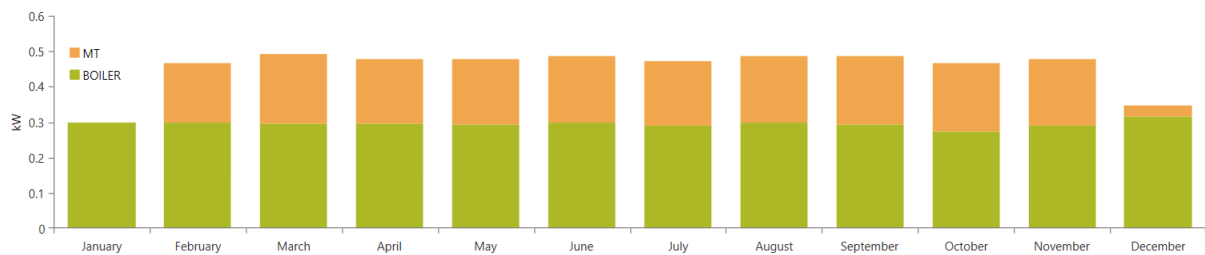


Figure 5-43: Monthly based Average thermal load

The MT (CHP) with 31.81 % of capacity factor and 107.1 % of electrical efficiency generates maximum electricity 3.0 kW and 0.6 kW thermal energy. The MT operates 5032 h per year and produces 8360.6 kW electricity shown in figure (5-47) and 1373.3 kW thermal energy with 148 throughout the year. The MT (CHP) operates by biomass, the specific biogas consumption with 0.02 kg per kWh and 7.3 kg per year shown in figure (5.48). The specific fuel consumption 0.61 L per kWh and total fuel consumption 7.30 L per year.

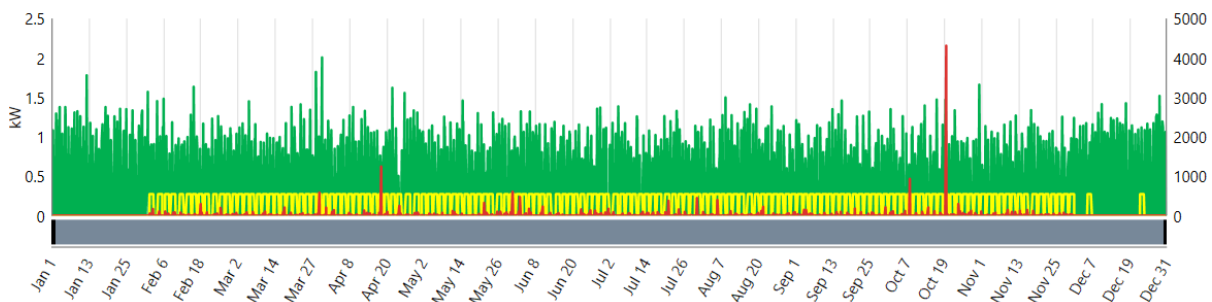


Figure 5-44: Thermal Energy Production (yellow) load (green) and excess (red)

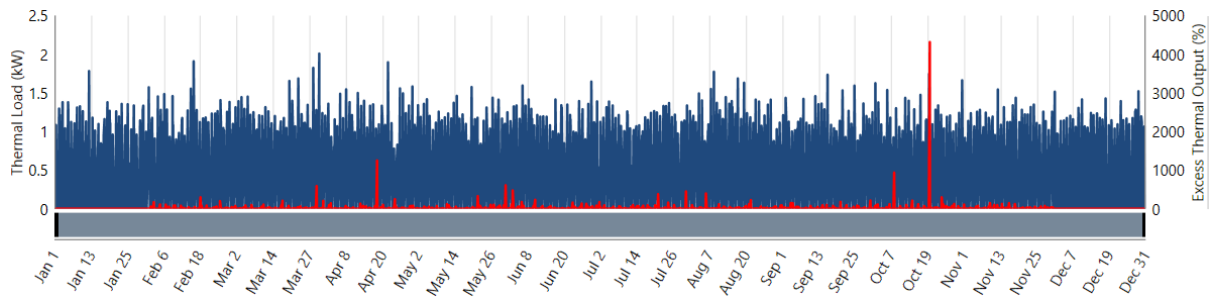


Figure 5-45: Thermal Load (blue) and Excess thermal Load (red)

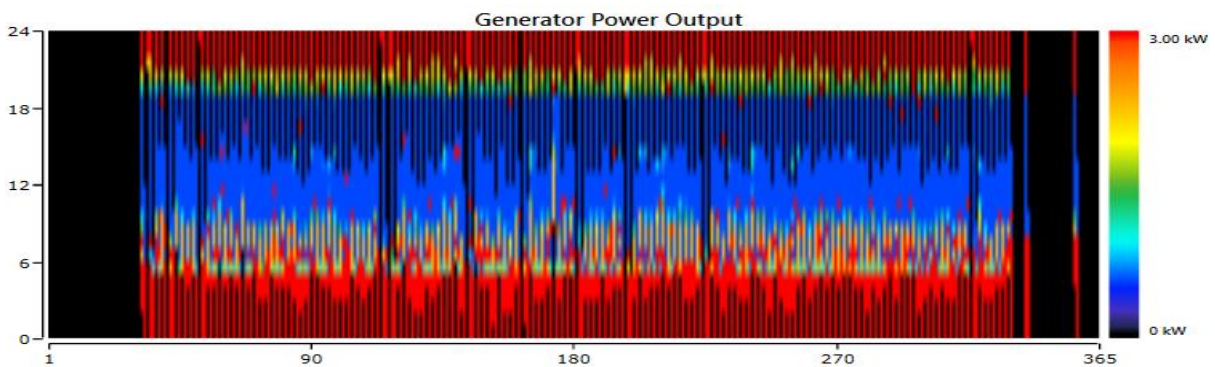


Figure 5-46: MT (CHP) optimal output electrify

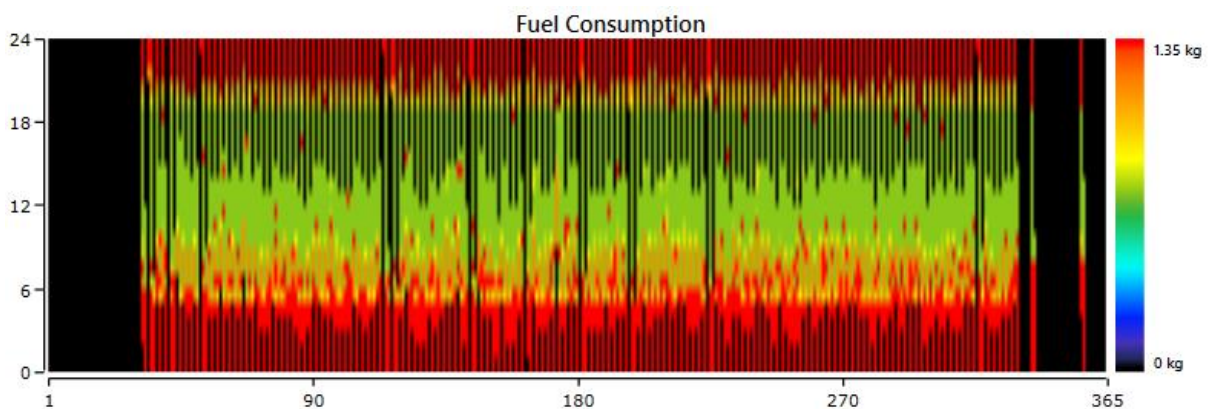


Figure 5-47: Fuel Consumption by the MT (CHP)

The renewable generation divided by the load about 29.21 %, and renewable production divided by generation is about 26.08 %. About 81.1 % of renewable energy fraction observed in scenario-4, and the non-renewable production divided by the load is 17.19 % shown in figure (5-49). During daytime demand of peak load is lower than evening and PV produces electricity in the daytime, as battery stores electricity from PV. Configuring 20 battery in parallel strings (each string 1 battery with 83.4 Ah) considered in the

system, and 1,978.3 kWh throughput per year and battery losses 430.62 kWh per year. The monthly average state of charge (SOC) shown in figure (5-50).

The inverter and rectifier operates 3478 h and 3307 h per year, the PV generated surplus electricity supplied to the main grid through inverter shown in figure (5-51). Both residual and cold storage load connected in DC bus; PV generated electricity delivered, stored without any converter except sell back to the grid. The MT generated electricity delivered through rectifier (the electricity transform AC to DC) to the load, the surplus electricity from PV and battery sell back through inviter to the main grid shown in Figure (5-51) and the conversion of electricity shown in figure (5-52) Inverter (top) and Rectifier (down).

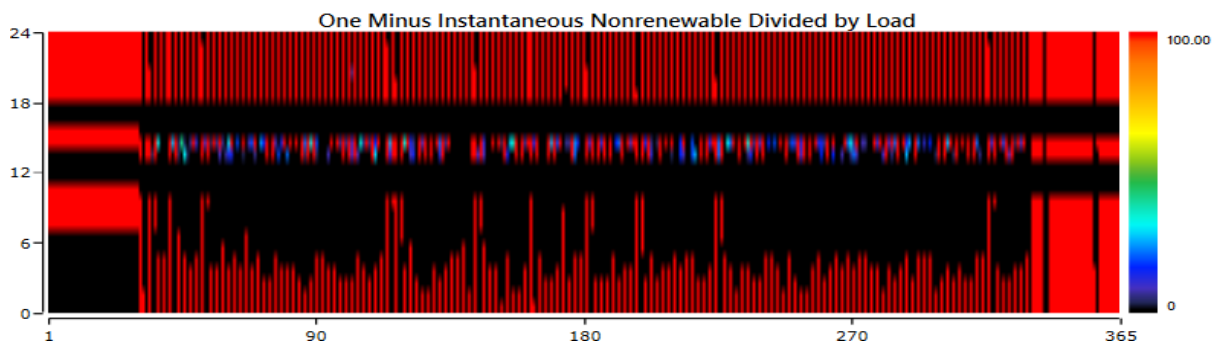


Figure 5-48: Non-renewable energy divided by load

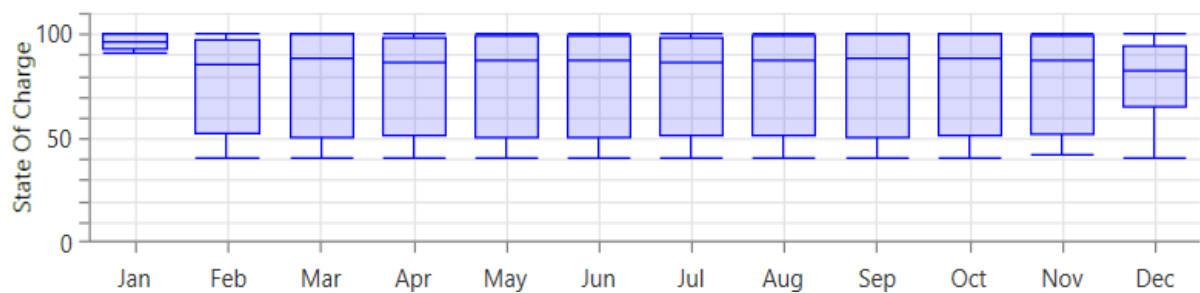


Figure 5-49: SOC of Batteries

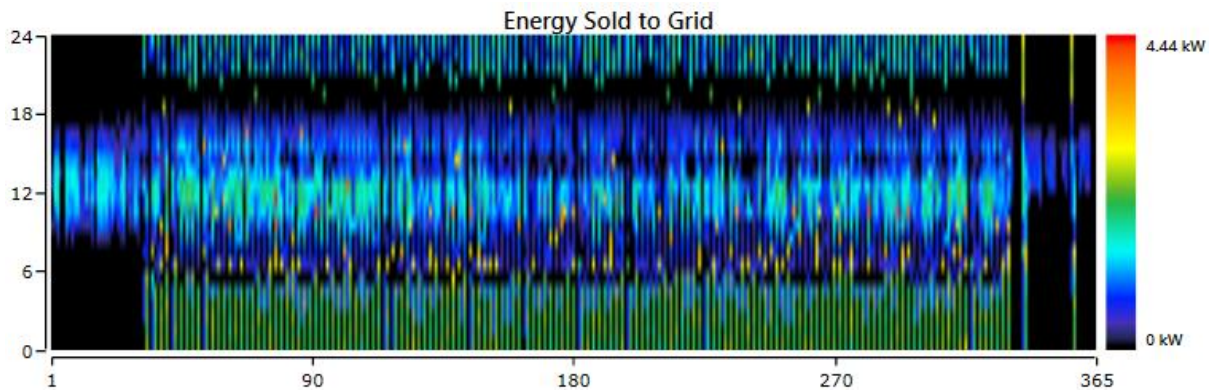


Figure 5-50: Electricity Sell back to the grid

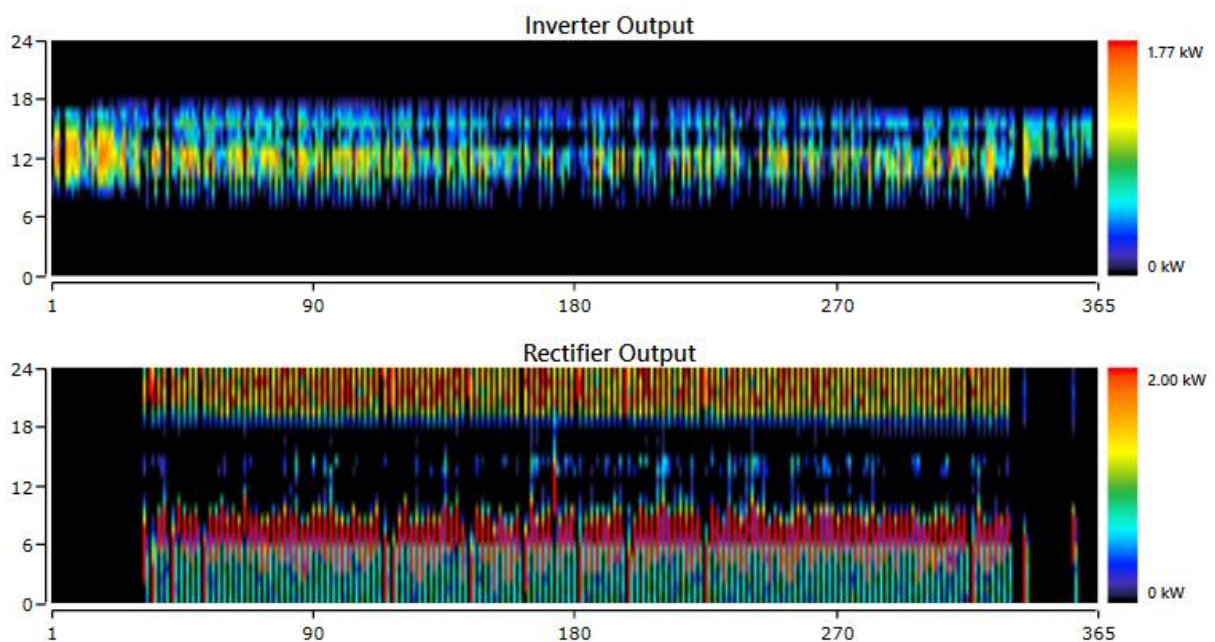


Figure 5-51: Converter: Inverter (top) and rectifier (down)

5.3.4.2 Grid Connected MG: Cold storage connected in DC bus

An external grid connected configuration consisting of 2.0 kW of PV and 2.5 kW of MT (CHP) generates in total 14,098 kWh electricity per year shown in figure (5-53); shade brown histogram represent PV and light rust histogram represent MT produced electricity. The PV module with 16.83 % of capacity factor energy produces 8.08 kWh per day. The maximum output of 1.98 kW PV generated and about 67.34 % PV penetrates in the system, total electricity produces 2,949.4 kWh by the PV per year. The electricity generates 20.92 % and 79.02 % by PV module and MT (CHP) respectively. As Load requires 4380 kWh per year, which is 33.17 % of the total produced electricity produces

by the sources. The surplus 8658 kWh of electricity sell back to the grid per year. The remained surplus electricity sell back to the grid through inverter shown in figure (5-54) and electricity quantity and sell back to the grid price depicted in the table (5-8).

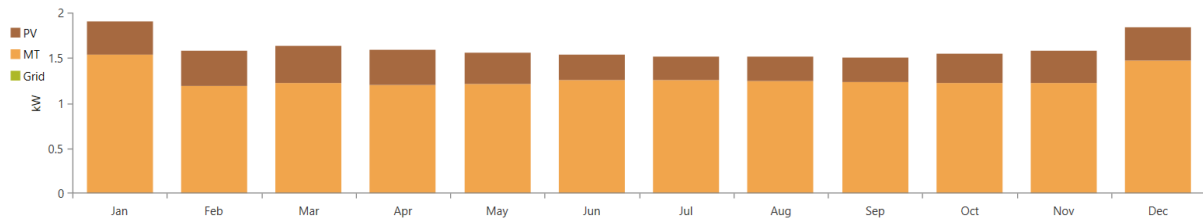


Figure 5-52: Monthly based average electricity generation

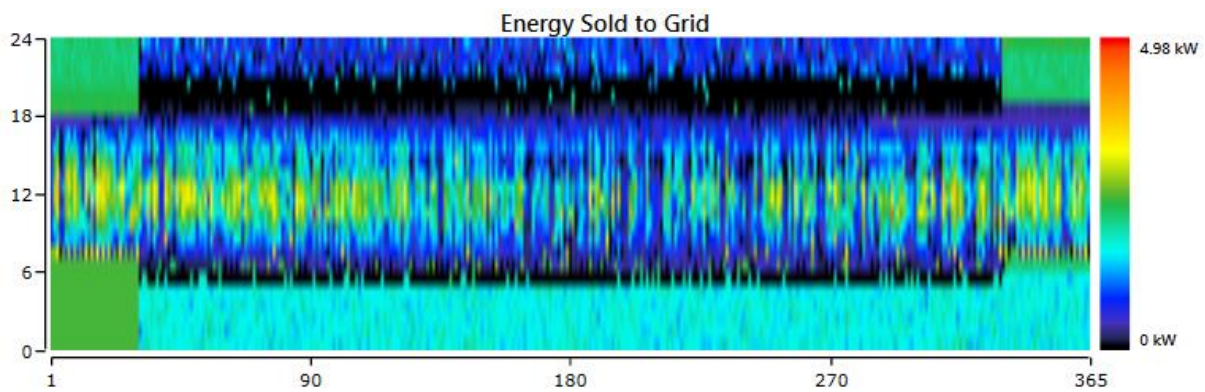


Figure 5-53: Surplus Electricity sellback to the grid

In the system MT (CHP) operates 7234 h and produces 11,148 kWh electricity shown in figure (5-37) and the generators output shown in (5-55). Thermal energy produces by MT and boiler shown in figure (5-56), where both MT and boiler produces 38.58 % and 61.42 % respectively.

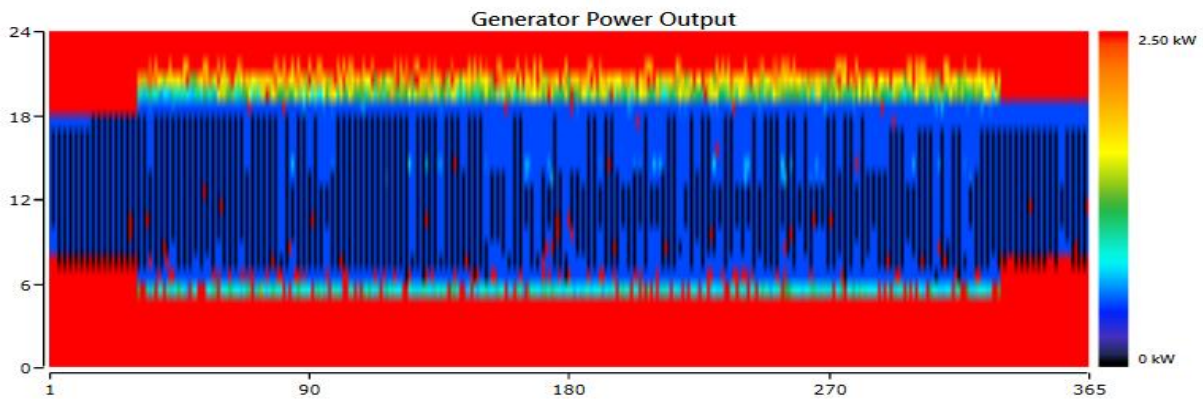


Figure 5-54: Generator Output

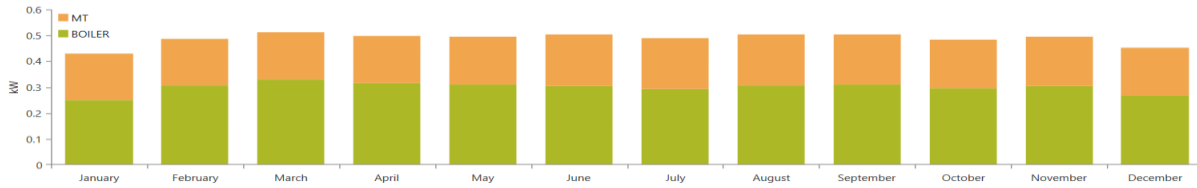


Figure 5-55: Thermal Energy output of MT and boiler

The maximum renewable penetration in the system as renewable fraction 89 % rebelled in Homer simulation. There is no excess electricity in this optimal configuration. In figure (5-57) the violate spike and red spike represents, the surplus Electrify sellback to grid and Unmet Load respectively. The unmet load precisely present in the figure (5-58), it is precisely shows that the unmet load is zero except weekend load demand is comparatively low as ability to sell back to the grid. In figure (5-58), the blue rounded rectangle spike present 12 April 2013 and 13 April 2013, and black rounded circle also represent weekend days.

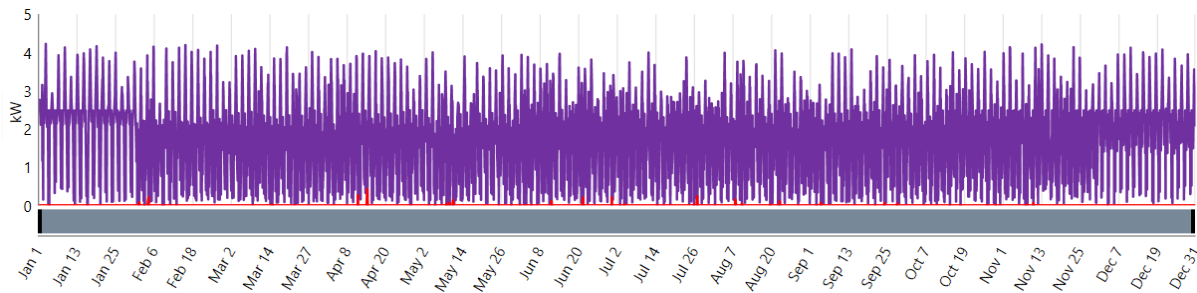


Figure 5-56: Sellback surplus electricity (violet) and unmet load (red)

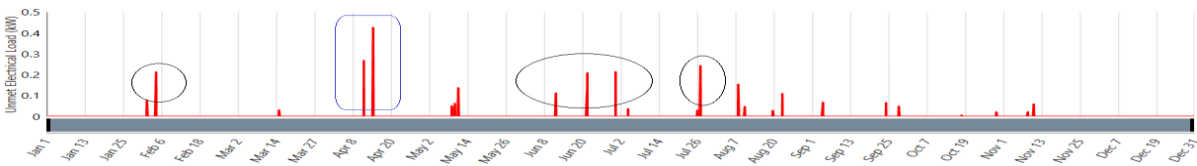


Figure 5-57: Unmet load

Surplus Electricity sellback to the Grid

When optimal system produces enough energy by peak solar power after meet up loads and battery SOC at 90 %, of the surplus electricity directly sellback to the grid. The electricity sellback to the grid has considered through the two assumptions as bellow;

Assumption-1: Weekday price (peak price)

The grid power price 0.1 (\$/kWh) and sellback price 0.05 (\$/kWh); the surplus 12,454 kWh electricity sellback to main grid per year present in the table (5-3). The optimum configured MG has ability to earn \$ 622.7per year.

Assumption-2: Weekend day price (shoulder Price)

The grid power price 0.03 (\$/kWh) and sellback price 0.01 (\$/kWh); the surplus 7043 kWh electricity sellback to main grid per year present in the table (5-3) and total earning by sellback to the main grid.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (\$)	Demand Charge (\$)
January	0	188	-188	0	(\$1.88)	\$0
February	0	472	-472	0	(\$4.72)	\$0
March	0	590	-590	0	(\$5.90)	\$0
April	0	534	-534	0	(\$5.34)	\$0
May	0	546	-546	0	(\$5.46)	\$0
June	0	477	-477	0	(\$4.77)	\$0
July	0	468	-468	0	(\$4.68)	\$0
August	0	506	-506	0	(\$5.06)	\$0
September	0	493	-493	0	(\$4.93)	\$0
October	0	571	-571	0	(\$5.71)	\$0
November	0	530	-530	0	(\$5.30)	\$0
December	0	180	-180	0	(\$1.80)	\$0
Annual	0	5,555	-5,555	0	(\$55.55)	\$0

Figure 5-58: Surplus Electricity sellback to the grid (peak price)

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (\$)	Demand Charge (\$)
January	0	188	-188	0	(\$9.41)	\$0
February	0	760	-760	0	(\$37.98)	\$0
March	0	829	-829	0	(\$41.46)	\$0
April	0	779	-779	0	(\$38.95)	\$0
May	0	765	-765	0	(\$38.23)	\$0
June	0	707	-707	0	(\$35.34)	\$0
July	0	740	-740	0	(\$36.99)	\$0
August	0	715	-715	0	(\$35.74)	\$0
September	0	704	-704	0	(\$35.19)	\$0
October	0	790	-790	0	(\$39.48)	\$0
November	0	778	-778	0	(\$38.88)	\$0
December	0	1,030	-1,030	0	(\$51.52)	\$0
Annual	0	8,783	-8,783	0	(\$439.16)	\$0

Figure 5-59: Electricity Purchased and sellback to Grid (shoulder price)

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (\$)	Demand Charge (\$)
January	0	1,323	-1,323	0	(\$13.23)	\$0
February	0	610	-610	0	(\$6.10)	\$0
March	0	680	-680	0	(\$6.80)	\$0
April	0	634	-634	0	(\$6.34)	\$0
May	0	638	-638	0	(\$6.38)	\$0
June	0	597	-597	0	(\$5.97)	\$0
July	0	613	-613	0	(\$6.13)	\$0
August	0	608	-608	0	(\$6.08)	\$0
September	0	578	-578	0	(\$5.78)	\$0
October	0	636	-636	0	(\$6.36)	\$0
November	0	640	-640	0	(\$6.40)	\$0
December	0	1,101	-1,101	0	(\$11.01)	\$0
Annual	0	8,658	-8,658	0	(\$86.58)	\$0

Figure 5-60: Surplus Electricity sell back to the grid (peak price)

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge (\$)	Demand Charge (\$)
January	0	1,657	-1,657	0	(\$82.87)	\$0
February	0	1,129	-1,129	0	(\$56.44)	\$0
March	0	1,251	-1,251	0	(\$62.57)	\$0
April	0	1,207	-1,207	0	(\$60.37)	\$0
May	0	1,233	-1,233	0	(\$61.66)	\$0
June	0	1,269	-1,269	0	(\$63.44)	\$0
July	0	1,279	-1,279	0	(\$63.93)	\$0
August	0	1,278	-1,278	0	(\$63.90)	\$0
September	0	1,228	-1,228	0	(\$61.40)	\$0
October	0	1,267	-1,267	0	(\$63.33)	\$0
November	0	1,276	-1,276	0	(\$63.80)	\$0
December	0	1,521	-1,521	0	(\$76.02)	\$0
Annual	0	15,594	-15,594	0	(\$779.72)	\$0

Figure 5-61: Surplus electricity sell back to the grid (shoulder price)

Both Case-1 and case-2; during weekdays the peak price considered grid purchase price 0.1 \$/kWh and sell back price 0.5/kWh. The figure (5-59) and (5-61) represent the amount of surplus electricity sell back to the grid and amount of money earned by the MG. As shown in the figure (5-59) and (5-61), case-1 sell back about 5555 kWh and earns \$ 55.55 per year, whereas case-2, 8658 kWh surplus electricity sell back to the grid and earns \$ 86.58.

Weekend period the grid purchase considered as 0.03 \$/kWh and sell back price as 0.01 \$/kWh, case-1, 8783 kWh surplus electricity sell back to the grid and earns 439.16 \$ earns through the year. For case-2; 15,594 surplus electricity sell back to the grid and earns about 779.72 \$ earns in each year present in figure (5-60) and (5-62).

5.4 MG Components Configuration and Sizing

An autonomous off grid or grid tied renewable energy integrated power system configured with optimal positions, planning for suitable components and appropriate size of components that offers reliability and flexibility in the system. According to rural electrification, the bottom up concept used to more favourable in Bangladesh [171]. In the configured with PV and biomass, both PV and biomass are the major source of energy. The power system formed along with PV modules, biomass fuelled CHP, and loads.

5.4.1 PV Modules Sizing

Large SHS configuration

The large SHS module sizing: To size the PV modules, initially demand of load consumption requires.

Table 5-3: Large SHS load and consumption energy

Appliance	Rated Capacity	Operation (h)		Total energy		Energy consumption	
		Summer	Winter	Summer	Winter	Summer	winter
CFL (4)	6 W	5	5	30	30	120	120
Ceiling fan (4)	60 W	8	0	420	0	1920	0
M. Charger (2)	3 W	3	3	9	9	18	18
TV (1)	20 W	5	5	100	120	100	100
Total energy consumption (kWh/day)						2.158	0.358

The large SHS summer energy consumption about 2.158 kWh per day while winter energy consumption about 0.358 kWh per day. The proposed system site in the Bangladesh, where the winter considered only two months. Hence the system configures and sizing respect to the summer season.

$$\begin{aligned} \text{Energy consumption by the appliances} &= 2.158 \times 1.2 \\ &= 2.5896 \text{ kWh per day} \\ \text{The Watt-peak of PV panel} &= 2590/5.99 \\ &= 432 \text{ W}_P \end{aligned}$$

$$\begin{aligned} \text{The Large SHS panel short circuit (Isc) considered as } &5.99 \text{ A} \\ \text{Number of PV module needed for large SHS} &= 432 \text{ W}_P / 65 \text{ W}_P \\ &= 6.646 \end{aligned}$$

The large SHS configuring with 7 PV module and loss factor assumed 1.2

Regular SHS module sizing

Sizing the regular SHS by configures the PV modules, initially load energy consumption requires and loss factor 1.2 considered to reliable and stable system.

Table 5-4: Regular SHS loads and Energy Consumption

Appliance	Rated Capacity	Operation (h)		Total energy		Energy consumption	
		Summer	Winter	Summer	Winter	Summer	winter
CFL (3)	6 W	5	5	30	30	90	90
Ceiling fan (3)	60 W	8	0	420	0	1440	0
M. Charger (1)	3 W	3	3	9	9	9	9
TV (1)	20 W	5	5	100	120	100	100
Total energy consumption (kWh/day)						1.639	0.20

$$\begin{aligned}
 \text{Energy consumption by the appliances} &= 1.639 \times 1.2 \\
 &= 1.966 \text{ kWh per day} \\
 \text{The Watt-peak of PV panel} &= 1966/5.99 \\
 &= 328 \text{ W}_P
 \end{aligned}$$

$$\begin{aligned}
 \text{The Large SHS panel short circuit (Isc) considered as } &5.99 \text{ A} \\
 \text{Number of PV module needed for large SHS} &= 432 \text{ W}_P / 65 \text{ W}_P \\
 &= 5
 \end{aligned}$$

5.4.2 Battery Sizing

The configuration and sizing of battery requires appliances consumption, nominal system and battery voltage, and battery autonomy (days). Assuming, the battery nominal voltage 12 V, battery loss 85 % and depth of discharge 60 % considers to design the battery capacity. Battery autonomy considered 2 days.

$$\begin{aligned}
 \text{Battery capacity} &= \frac{\text{Energy Consumption}}{\text{Battery volatge} \times \text{Battery losses} \times \text{Battery DOD}} \\
 &= \frac{2280 \text{ Wh}}{12\text{V} \times 0.85 \times 0.6} \times 2 \text{ days} \\
 &= 740 \text{ Ah}
 \end{aligned}$$

So a large SHS battery should be rated for 12 V system about 740 Ah for 2 days.

The configuration and sizing of battery requires appliances consumption, nominal system and battery voltage, and battery autonomy (days). Assuming, the battery nominal voltage

12 V, battery loss 85 % and depth of discharge 60 % considers to design the battery capacity. Battery autonomy considered 2 days.

$$= \frac{1966\text{Wh}}{12\text{V} \times 0.85 \times 0.6} \times 2$$

$$= 643 \text{ Ah}$$

For the regular SHS, the battery should be rated for 12 V system about 7642 Ah for 2 days.

5.4.3 Charge controller Sizing

The charge controller sizing depends on PV configuration and most importantly the parameters of the of PV module. PV module parameter specifications

Parameters	
Peak power (W_P)	= 65 W
V_{MPP}	= 28V
I_{MPP}	= 5.75
I_{SC}	= 5.99
V_{OC}	32.1

Charge controller sizing for large SHS	= 7 string *5.99 A
The large SHS charge controller configuration should be	= 41.93 A or 42 A
Regular SHS charge controller configuration should be	= 30 A

Summary

The configuration and design optimization to analyse the potential to introduce energy access from locally available biomass and stand-alone PV system integrated scheme for the remote area in Bangladesh. The suggested system configures with the future demand that considers along with load power about 33,228 kWh and 8,743 kWh for summer and winter per day respectively. Both household and cold storage electrical load power consider as 5 % of day-to-day random variation and load factor 0.2. The suggested system households peak load demand from around 19:00 h to 23:00 h. Three different configurations studied based on exclusively on PV, CHP, and batteries, and some configuration considers along with main grid. The planning for configuring standalone PV and biomass fuelled MG system, optimization considered to meets the load power effectively and efficiently. The optimum sizing and configuration of each component that minimizes the cost of the system, but optimal output meets the demand. The system design in the different configuration such as standalone DC MG, grid connected MG and AC-DC combinational MG. The standalone DC-MG configuration consists of PV modules, batteries, DC-MT (CHP), all loads including household and cold storage connected to DC bus. AC-DC combinational MG associates along with DC and AC bus; the PV modules, household loads, and batteries connected in DC bus. The MT (CHP) produces AC power and cold storage connected to either AC bus or DC bus through the converter. Grid connected MG encompasses along with both AC and DC bus; household load, PV module and battery coupled to DC bus, and MT (CHP) tied with the grid in AC bus. The studies also allow the cold storage allied in DC bus or AC bus.

The (MT) CHP produces electricity and thermal energy with 100 % of electrical efficiency and 45 to 50 % heat recovery respectively. The cold storage consumes both electricity and thermal energy that produced by the (MT) CHP. Although the cold storage consumes chill air, moreover by using absorption chiller the thermal energy adapts into the chill air. The cold storage consumes about 9.79 kWh to 15.7 kWh during winter and summer per day respectively, and optimization considers at 5 % day-to-day random variation. Both winter and summer the thermal peak load from around 11:00 h to 15:00 h, as well as electrical power. The optimization of configuring the MG by using Homer tool based simulation for best suitable configuration; where the variable size of PV modules, MT

(CHP) generators, battery, and converters offer optimal design. The simulation of configuring and planning of MG, the electrical and thermal load Homer tool based on expected future demand in 2025 those including local biomass resources for the MT (CHP) fuel, solar insolation of PV module throughout the year. Standalone DC MG system, PV produces power is the main source of energy for household loads. However, MT (CHP) mainly used to generates thermal energy, which converts into chill air delivered to the cold storage, and produced electrical power that delivered into the system. The optimal configuration considered 2.1 kW PV and 1.7 kW MT, and associate system produced 8,000 kWh per year. The optimum system offers 41 % of PV power and 49 % of MT (CHP) power, PV module operates 4,370 h.

The grid connected MG configured to sell back surplus electricity to the grid. The PV module operates average 11 h per day and 4,370 h throughout the year. The optimal sizing and configuration of PV module and MT (CHP), which is important exertion for the planning of MG that meets both electrical and thermal power of the system. Studied among all configurations, the system offers about 70 to 90 % of the renewable fraction. Although this report does not, comprises any economic feasibility but mostly preferred technical appraisal considered for the well-suited MG system. A fully renewable-based MG that has almost zero CO₂ emission, but the net present cost (NPC) is reasonably high. During daytime, the system offers 100 % of renewable power generation and consumption.

DC microgrid, 0.4 kW of PV does not comply the total load power, as MT (CHP) produces rest of the power to meet the load power. But MT does not produce enough thermal to comply the desires thermal load. The system configured with 0.4 kW of PV and 1.6 kW of MT produced excess electricity about 600 kWh per year. The surplus power can be delivered to the community based water pump for irrigation for development purpose. The grid connected MG configuration the surplus electricity sell back to the grid, in (case-2) the amount of sell back electricity larger than (case-1).

Chapter 6

Conclusion and Future work

6.1 Concluding Remarks

In this thesis, author represents a proposal of the new configuration of the modern power system for rural electrification, the scheme form by integrating several solar home system and CHP, the author also found the opportunity of biomass fuelled power generating system in Bangladesh. The goal is to achieve energy access in non-electrified areas by renewable energy integrated innovative rural electrification approach, the optimal design with renewable energy source integration in the proposed MG system, the demand side complemented by the locally distributed sources. The modelling of MG from the theoretical point of view of each element of the system, and theatrical equations, and data have been considered in MATLAB/SIMULINK environment.

The present work focus mainly on grid-tied and stand-alone mode operation of MG, the model developed along with 20 households including 12 SHS, and 8 BHS those all connected to the grid through bidirectional converters to maintain the reliable and stable system under constant loads considered and also control strategy studied. The MPPT P&O algorithm has used to get the maximize the power from the PV panel, and centralized controller of MG control the power exchange in-between AC and DC system, share power among all SHS and BHS. In standalone mode, the proposed system operates as DC-MG, each converter coupled with an SHS and power level transform in between 12 to 24 V or 12V to 48 V. The pole mounted transformer used in the AC/DC system to reduces electric loss, and the most cost effective electrical distribution components.

The cold storage can be connected to the DC bus in MG, a DC microturbine can be used to produces electric power and thermal power or directly to loads without the grid. The thermal energy converts into the chill air by thermal driven absorption chiller. The advantage of μ -CHP system has the ability to improve both electrical and thermal efficiency 33 % and 65 % respectively.

In chapter 1, the general introduction of thesis work and motivation has been discussed, while, the aim of the report also discussed to comply the motivation of the thesis.

In chapter 2, has described total electricity access to Bangladesh, the development and GDP index of a country depends on a country's continuous production, a country like Bangladesh which is agrarian offer enormous biomass potential to produce electricity

simultaneously thermal energy. The low income developing country like Bangladesh per capita GDP has increased by consuming 1 % of energy. The growth rate of electricity is increasing from 5.5. % to 13.2 % in last 5 years and access to electricity achieved about 59 % of total population. At present, the total electricity has produced 12,171 MW by 2015, whereas 10,445 MW in 2012. In Bangladesh, power sectors comprise with private and public sector along with Power Grid Company Bangladesh (PGCB) only company to engage in transmission of power across the country and other enterprises engage in distributing power including urban and rural areas. Although there is only Bangladesh Rural Electrification Board (BREB) employed to electrifies in the rural areas. Almost 90 % of electricity have produced by the conventional fossil including gas, coal, and furnace oil, while natural gas serve is not enough to produce sufficient amount of electricity. Moreover, the electricity produces by imported coal, furnace oil, and (independent Power Producers) IPPs, which is the expensive to the end users, without subsidies of GOB it would be almost impossible to use electricity for the low and middle-income inhabitants in Bangladesh.

Since renewable energy emerging into the Bangladesh's power sector since 1994, the growth achieved 2 % of total electricity production by 2014. The GOB has stabilized Infrastructure Development Company Limited (IDCOL) in Bangladesh to promote renewable energy development to compliant socio-economic development. In 2003 solar program started, while IDCOL promoted solar home system across the country and reached 3 million SHS installation and become the market leader. Since 2009 GOB dedicated policy and reforms towards Renewable Energy policy of Bangladesh, which having envisions including 5 % power achieved by 2015, 10 % by 2020, and 20 % by 2035. Geographically blessed Bangladesh receives an average 4-6 kWh/m² daily solar irradiation promotes a high number of the solar home system across the rural and remote areas, and the number increases at 58 % in each year. The government has taken several approaches to promote renewable energy across the country by established Sustainable Renewable and Energy Development Authority (SREDA) and IDCOL.

At present studies about 55.41 % population as estimated 5.05 million households has electrified by Bangladesh Rural Electrification Board (BREB) and Palliy Biyduit Samity (PBS) working as cooperative organization. Among IDCOL, SERDA, BREB working together for 100 % of electrification in rural areas, while 95 % of households will be

decreased their kerosene consumption about 1.7 litres compare to those not yet electrified. Complementing the "vision 2021" and Millennium Development Goal (MDG) the renewable energy integrated power system considered the ultimate solution for power shortage in Bangladesh.

In Chapter 3, the details concept of MG and its elements described. Being shortage of finite stock of natural gas, and use of imported coal and furnace oil in power generation that have the negative impact on the environment. When the world faces the shortage of electricity, and learning new practice towards renewable energies such as solar PV, biomass, hydropower, and wind energy ensure energy security. Standalone solar PV system, especially SHS has been a significant growth across the rural areas in the country throughout last five years in Bangladesh. The research investigates and demonstrates, the PV technology adaptability and flexibility for designing in different regions with the different scheme. In the remote areas, it is straightforward to design the stand-alone system which possible to adopt with bottom up swarm concept, where energy can be sharing among participants' in the system. Similarly, the country like Bangladesh, where biomass potential has seen enormous prospective to produce electricity by small scale CHP or micro-generator. Almost 2.0 tons/day production of biomass resources available from agricultural based regions, where agricultural biomass waste and animal manure used a fuel and the process considers either gasification or combustion taken into consideration to produces 35 % of electrical power and 75 % of thermal energy from micro-CHP.

The studies show inclusive of decentralized electric power generates by several SHS and m-CHP, among all SHS coupled in parallel in the DC bus and followed by the radial network. Improving the efficiency both DC MG system and distribution, a dispatching model that comply by optimal size design, planning for desire operation strategy for the specific application. The efficiency also depends on a number of converter and charge controller used in each SHS, load power consumption, battery capacity and SOC, while DOD considers 70 % to 60 % that prolongs the SOC of lead acid battery and battery charge cycle considered as 40 % to 100 %. In the system charge controller are important elements that control the system that ensure stable and reliable operation. The MPPT algorithm P&O ensures harnessing the maximum power from PV and best utilization of solar power in PV system.

In chapter 4 comprises of results and discussion, each component of MG model and design based on MATLAB/SIMULINK environment. The main and important elements of the MG is PV module; the model has designed based on temperature dependency which also conferring solar insolation. The solar PV module designed by the theoretical equation and the temperature dependency defined by the equation ($TC = T_a + 0.03 \times G_a$). The cell temperature of PV module varies follows by the fluctuation of solar irradiation and ambient temperature of the location, while increases in temperature reduce the band gap of a solar cell. By increases the temperature, internal carrier combination increases while cell performance decreases instantaneously. The ambient temperature is extremely sensitive to the wind speed, and the PV cell temperature rises over ambient, while solar cell temperature also strongly depends on solar irradiation. The suggested power system, battery-based energy storage plays an important role, and charge controller allows reliable operation. The SHS including PV module, battery, and charge controller modelling and simulation have also done in MATLAB/SIMULINK environment. In the standalone system, an SHS suggested a charge controller strategy and charge controller model to charged battery and controlled. An extensive investigation of each individual MG components model and configured by SIMULINK based simulation in MATLAB. The dynamic behaviour of MG distinguished the suitable configuration and design can be deployed in the proposed system. The controller operates within the system to maintain constant DC bus voltage to perform the stable system. The battery has designed as PV-generated current should not 10 % of battery capacity, and charge control operation accordingly. In the proposed system, each battery capacity of SHS or BHS has composed with 60 to 80 Ah. The proposed charge controller operation strategy for large SHS charging with maximum 5.99 A, regular size SHS charging with maximum 3.99 A current, while battery home system charger controller also charging with maximum 4 A. In the MG system, the SHSs enable to share their surplus electricity among all SHS and BHS connected to the DC bus, while the battery state of charge considered as (SOC \geq 60 %) and the surplus electricity delivered to the DC bus. Additionally, battery state of charge at (SOC \geq 90 %), excess electricity sells back to the main grid.

In chapter 5 describes the optimal MG design, where PV system and CHP integrated configuration offers optimum output and result has discussed by simulating Homer Pro tool, the planning and sizing of MG system studied through the chapter. The optimal size

each element of MG and configuration minimize the cost of the system. Although this thesis economic and financial studies not considered and discussed. A typical rural area in Bangladesh, electricity consumption in the peak load considering the range 4 kW to 20 kW, and energy consumption about 100 kWh to 300 kWh per day. The configuration and design optimization to analyze the potential to introduce energy access from locally available biomass and stand-alone PV system integrated scheme for the remote area in Bangladesh. The suggested system configures with the future demand that considers along with load power about 33.228 kWh and 87.43 kWh for summer and winter per day respectively. There are several configurations studied based on exclusively PV, CHP, and batteries, and some configuration also coupled with the main grid. The optimum size of each element of MG and configuration minimize the cost of the system. The main grid connected configured MG have the ability to produce surplus electricity that sells back to the grid. The (MT) CHP produces electricity and thermal energy with 100 % electrical efficiency and 45 % to 50 % heat recovery respectively. The cold storage consumes both electricity and thermal energy that produced by the (MT) CHP. Although the cold storage consumes chill air, moreover by using absorption chiller the thermal energy adapts into the chill air. The cold storage consumes about 9.79 to 15.7 kWh. The simulation of configuring and planning of MG, the electrical and thermal load Homer tool based on expected future demand in 2025 those including local biomass resources for the MT (CHP) fuel, solar insolation of PV module throughout the year. Standalone DC MG system, PV produces power is the main source of energy for household loads.

Studied among all configurations, the system offers about 70 % - 90 % of the renewable fraction. Although this report does not, comprises any economic feasibility but mostly preferred technical appraisal considered for the well-suited MG system. A fully renewable-based MG that has almost zero CO₂ emission, but the net present cost (NPC) is reasonably high. During daytime, the system offers 100 % of renewable power generation and consumption. The DC microgrid configures with 0.4 kW of PV does not comply the total load power, as MT (CHP) produces rest of the power to meet the load power. But MT does not produce enough thermal to comply the desires thermal load. The system configured with 0.4 kW of PV and 1.6 kW of MT produced excess electricity about 600 kWh per year. The surplus power can be delivered to the community based water pump for irrigation for development purpose.

6.2 Future Work for Research

In the modern power system, the amount of distributed sources increases as complexity also increases simultaneously, and the performance of the system complemented always by the control system. Although the distributed sources in power system enhance flexibility in operation but without proper control offer reliability and stability. Further research and analysis can develop based on purely DC power system modelling and configuration including SHS, DC loads, biomass-fuelled large scale DC generator. The MG control system design and research based on droop control, each SHS energy management system also focus on droop control strategy. An adaptive droop controls modelling and investigate the flexible performance and reliable operation.

The research will also focus on the planning of poly-generation system and storage system, while a new configuration of DC microgrid where less use of electronics devices. As DC network helps to decrease the loss factors that increases the efficiency. The system model integrated with renewable sources as intermittent; modelling and simulation will consider dynamic load and dynamic pricing. The new configuration system will be modelling with load flow supply, the strategy entails of adapting the consumption illustration to the electricity production availability which can be influenced the end users.

The Power system configuration and DC power flow modelling and simulation based on ETAP software which complies IEEE-946 standard and, the flexibility and performance enhanced by IEC 61850, which gives flexibility in performance and system also allow AC grid interface and centrally control system provides reliability by monitoring. The ETAP tools simulate in the real time system which enhanced electrical management through dynamic applications using distributed SCADA technologies. The applications consist of dispatchers, capabilities of prediction, control, visualization, and automation in the power system. However, the web-based ETAP technologies location based information which optimizes the decision based on planned and unplanned event.

The MG system design and model in the PSCAD and MATLAB/SIMULINK especially decentralized control design and model for each SHS in SIMULINK environment that performs as reliable and stable energy management system. Likewise, a centralized

control system design in the system that controls the community based centralized energy storage. Another side investigates the feasibility of Battery home system and centralized energy storage. The controller configuration and design follow-up through back to the back converter, the converter and control modelling and simulation by MATLAB/SIMULINK.

An optimal configuration and design investigate of the smart power system for the rural electrification and standardize the model. The configuration encompasses with 80 or more SHS, the surplus electricity will store in the community based battery storage and households without PV system consume energy from the community based battery. A water pump may also include in the system to utilize the daylight sun.

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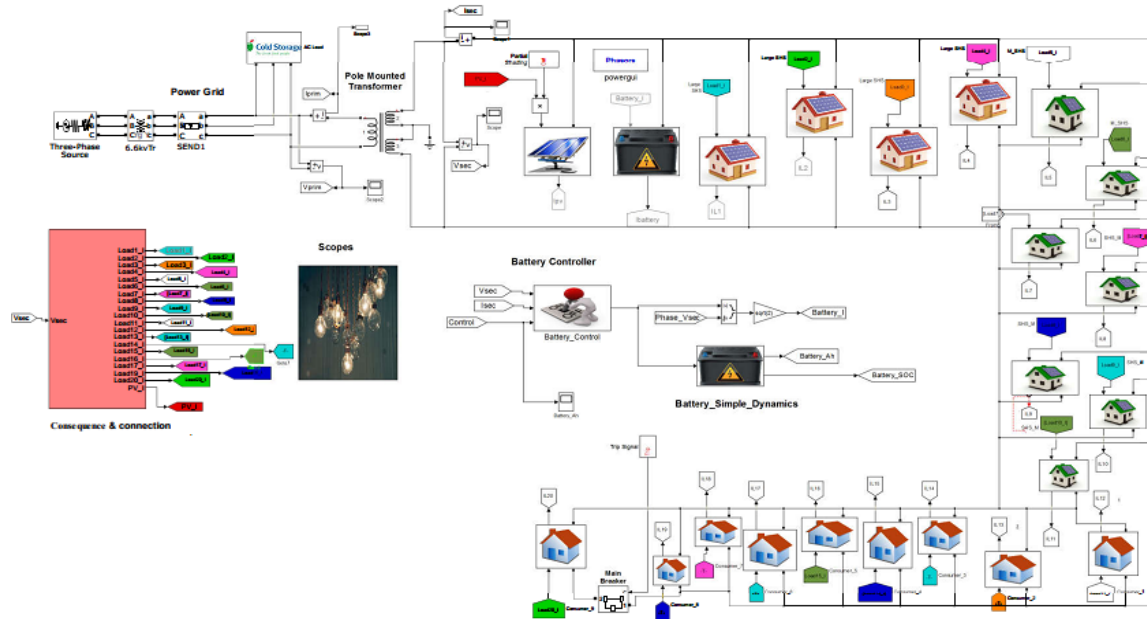
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APPENDIX - 1: Microgrid model in MATLAB/SIMULINK environment



Appendix-2: Kyocera Solar Module



THE NEW VALUE FRONTIER
KYOCERA

KC65T
HIGH EFFICIENCY MULTICRYSTAL PHOTOVOLTAIC MODULE

HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULES
Kyocera's advanced cell processing technology and automated production facilities produce a highly efficient multijunction photovoltaic module.
The conversion efficiency of the Kyocera solar cell is over 16%. These cells are encapsulated between a tempered glass cover and a postback with back sheet to provide efficient protection from the several environmental conditions. The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation.

APPLICATIONS

- Recreative / Florida repeater stations
- Electrification of villages in remote areas
- Medical facilities in rural areas
- Power source for summer vacation homes
- Emergency communication systems
- Water quality and environmental data monitoring systems
- Navigation lighthouses, and ocean buoys
- Pumping systems for irrigation, rural water supplies and livestock watering
- Aviation obstruction lights
- Cathodic protection systems
- Desalination systems
- Recreational vehicles
- Railroad signals
- Sailboat charging systems
- etc.

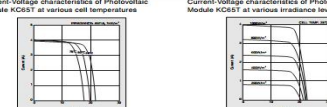
QUALIFICATIONS

- MODULE : UL 1703 certified
- INVERTER : CE, VDE, IEC, G, S, C and D
- FACTORY : ISO9001 and ISO 14001

QUALITY ASSURANCE
Kyocera multijunction photovoltaic modules have passed the following tests.
● Thermal shock test ● Thermal cycling test ● Thermal freezing and high humidity cycling test ● Electrical isolation test ● Salt mist test ● Mechanical, wind and hail loading test ● Salt mist test ● Light and water-exposure test ● Field exposure test

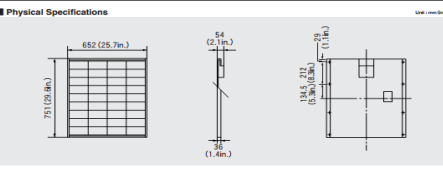
LIMITED WARRANTY
15 year limited warranty on material and workmanship.
10 year limited warranty on power output. The actual power will vary by temperature.
For more information and details of the limited warranty please refer to the "Warranty" section of the product manual or contact your local distributor. The power output guarantee shall be based on measured output (specify actual measurement). The actual power output will vary by temperature.

ELECTRICAL CHARACTERISTICS
Current-Voltage characteristics of Photovoltaic Module KC65T at various cell temperatures.



SPECIFICATIONS

Physical Specifications



64 (2.51in.)
71 (2.79in.)
18.5 (0.728in.)
2.5 (0.098in.)
1.6 (0.063in.)

Specifications

Electrical Performance under Standard Test Conditions (STC)	
Maximum Power (P _{max})	43W (1.19A, 3.6V)
Maximum Power Voltage (V _{mp})	3.7V
Maximum Power Current (I _{mp})	3.75A
Open Circuit Voltage (V _{oc})	4.17V
Short Circuit Current (I _{sc})	3.95A
Cell Efficiency	16.0%
Temperature Coefficient of V _{oc}	-2.2 to -2.3 / °C
Temperature Coefficient of P _{max}	-0.50 to -0.55 / °C

Electrical Performance at 2000h ₁ NOCT AM1.5	
Maximum Power (P _{max})	40W
Maximum Power Voltage (V _{mp})	3.5V
Maximum Power Current (I _{mp})	3.01A
Open Circuit Voltage (V _{oc})	3.97V
Short Circuit Current (I _{sc})	3.25A
Cell Efficiency	15.4%

Cells
Number per Module : 36

Module Characteristics

Length x Width x Depth	1810mm (69.29in.) x 650mm (25.59in.) x 35mm (1.38in.)
Weight	5.0kg (11.02lb)

Junction Box Characteristics

Length x Width x Depth	100mm (3.94in.) x 100mm (3.94in.) x 35mm (1.38in.)
IP Code	IP65

Reliability of Efficiency under Low Irradiance

Reduction	< 1%
Reduction of efficiency from an irradiance of 1000W/m ² to 200W/m ² inside temperature 25°C	< 1%

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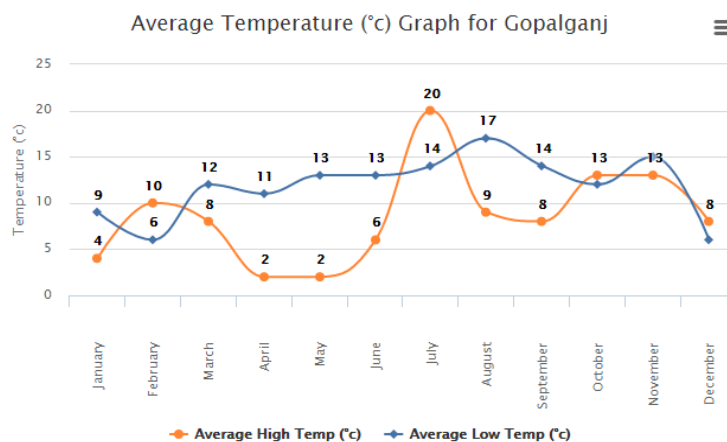
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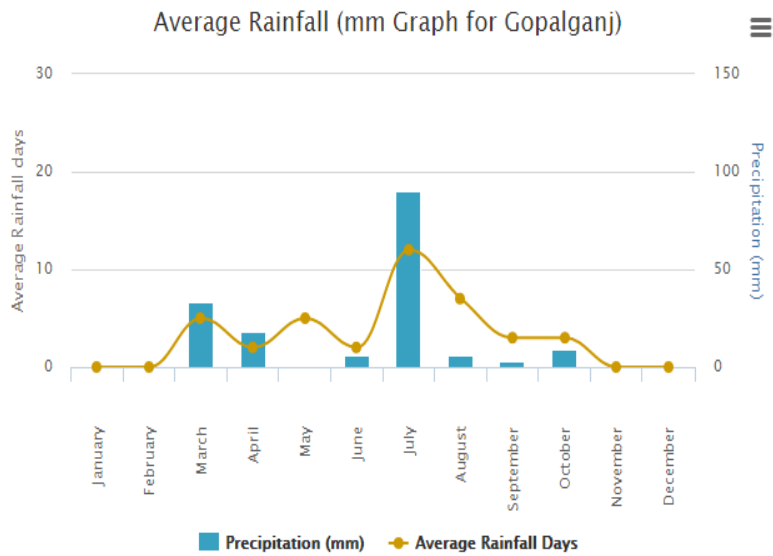
Appendix - 3: Matlab function for Battery control Startegy

```
Function [Discharging, Charging] = fcn(SOC)
%#codegen
Charging=1;
Discharging=1;
if (SOC<=30)
    Discharging=0;
    Charging=1;
end
if (SOC >= 30)&& (SOC >= 90)
    Discharging=1;
    Charging=1;
end
end
```

APPENDIX - 4: Average Temperature in Gopalgong, Bangladesh



APPENDIX – 5: Average Rainfall in Gopalgong, Bangladesh



the data for charts above are taken from year 2000 to 2012.

<http://www.worldweatheronline.com/gopalganj-weather-averages/bd.aspx>