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Techno-Financial Analysis of Grid Tied Solar Rooftop System
A Case Study on Star Homes, Sitapaila, Nepal

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled " Techno-Financial Analysis of Grid Tied Solar Rooftop System: A Case Study on Star Homes, Sitapaila, Nepal" submitted by Milana Prajapati in partial fulfillment of the requirements for the degree of Master of Science in Energy System Planning and Management.

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ABSTRACT

Most of the national energy demand is from the residential sector in Nepal. Thus, solar PV systems could be an attractive alternative for fulfilling the energy hungry residential sector converting each house as a power source. The objective of this thesis is to analyze the case to supply the required energy from the same demand point via the solar PV installed in the rooftop that is technically feasible. The survey is conveyed on the 20 out of 51 houses in Star Homes (Residential Sector) situated at 27°42'29.35"N latitude and 85°16'49.56"E longitude of Sitapaila, Kathmandu. There are three types of houses type 1, type 2 and type 3 categorized in this study according to their rooftop area and the load consumption pattern. The solar potential has been found to be 3.9 kWp, 4.8 kWp and 7.8 kWp in type 1, type 2 and type 3 houses respectively. Thus, the total solar potential of the Star Homes was found to be 252.8 kWp. For the comparative analysis in this thesis, the isolated PV system is designed/analyzed using PV-SYST and the grid tied PV including/excluding battery is designed/analyzed using SAM (System Advisory Model) software for three types of houses. According to the house type, there is maximum load of 1665 W, 2350 W and 4175 W for type 1,type 2 and type 3 house repectively. According to the load profile, the size of solar standalone system for type 1, type 2 and type 3 house is calculated to be 1620 Wp 26V/ 322Ah, 3240 Wp 51V/302 Ah and 6480 Wp 77V/412 Ah respectively. In standalone system, PVSYST simulation results show the designed system is capable to match the load of type 1, type 2 and type 3 with annual generation of 3067 kWh, 6300 kWh and 9592 kWh respectively and excess annual energy 795 kWh, 1744 kWh and 1429 kWh respectively. The LCOE considering 25 years life time with 7.5 % loan interest for 15 years for type 1, type 2 and type 3 is 0.21$, 0.21$ and 0.22$ per kWh.

The designed system of grid tied PV for type 1, type 2 and type 3 are 3.9 kWp, 4.8 kWp and 7.8 kWp respectively utilizing the available rooftop space. The SAM simulation results show the designed system is capable of annual generation of 6483 kWh, 7812 kWh and 12781 kWh respectively and the designed system is able to export energy 5645.45 kWh, 6680.83 kWh and 11277.03 kWh respectively. The net savings of electricity bill after installation of the system for type 1, type 2 and type 3 house is 516$, 635$ and 1018$ respectively. The LCOE considering 25 years life period with net metering and excess energy charged at 0.073$ for type 1, type 2 and type 3 are 0.0703$, 0.073$ and 0.0689$

respectively. The NPV considering 25 years life period with net metering and excess energy charged at 0.073$ for type 1, type 2 and type 3 are 2190$, 2585$ and 4429$ respectively.

The designed system of grid tied PV battery system for type 1, type 2 and type 3 are 3.9 kWp with 6.6 kWh battery, 4.8 kWp with 10 kWh battery and 7.8 kWp with 10 kWh battery respectively. The SAM simulation results show the designed system is capable of annual generation of 6415 kWh, 7722 kWh and 12692 kWh respectively and is able to export energy 4674.35 kWh, 4371.33 kWh and 8727.67 kWh respectively. The net savings of electricity bill annually after installation of the system for type 1, type 2 and type 3 house is 537$, 745$ and 1158$ respectively. Moreover, the maximum peak shaving achieved for type 1, type 2 and type 3 are 0.95 kW, 1.89 kW and 1.89 kW respectively. If all houses of Star Homes install such system, the total peak shaving that can be achieved is 92.6 kW. The LCOE considering 25 years of life period with net metering and excess energy charged at 0.073$ for type 1, type 2 and type 3 are 0.13$, 0.148$/ and 0.1152$ respectively. The NPV for type 1, type 2 and type 3 are -862$, -1188$ and 628$ respectively.

Moreover, the sensitivity analysis for type 1 house with different parameters has been presented with different outcomes. The major result show that the most profitable system is grid tied PV system without battery for residential houses supplied at grid tariff rate of block rate with net metering energy cost of 0.073$ per unit. Moreover, system with net metering and its sell rate at 0.073$ is profitable than the ppa rate as of hydropower. The NPV for grid tied PV with battery system is positive when loan rate is less than 5% and also positive for type 3 design with minimal battery size as of type 2 but higher PV size. Thus, higher PV integration with lower battery size is more suitable and profitable investment for residential load. The system peak shaving using battery storage technology is not profitable at all. However, such system relieves the grid during the peak time. As the peak load of Nepal is specially dominated by the residential load of lighting and cooking, with suitable policy and subsidy from the utility, the peak shaving in residential sectors would be fruitful in peak load management of INPS.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AC: Alternating Current

AD: Anno Domini

AEPC: Alternative Energy Promotion Center

BS: Bikram Sambat

CO: Carbon monooxide

CF: Capacity Factor

DC: Direct Current

DG: Diesel Gensets

DNI: Direct Normal Irradiancr

FNCCI: Federation of Nepalese Chamber of Commerce

GHG: Greenhouse Gas

GHI: Global Horizontal Irradiation

GW: Gigawatt

GWh: Gigawatt hour

GWp: Gigawatt peak

IFC: International Finance Corporation

INPS: Integrated Nepal Power System

IRR: Internal Rate of Return

IRs: Indian Rupees

JICA: Japan International Cooperation Agency

kV: Kilo Volts

kVA: Kilovolt Ampere

kW: Kilowatt

kWh: Kilowatt hour

kWp: Kilowatt peak

LCOE: Levelized Cost of Electricity

MoE: Ministry of Energy

MOEWRI: Ministry of Energy Water Resource and Irrigation

MPPT: Maximum Power Point Tracking

MW: Megawatt

MWh: Megawatt hour

MWp: Megawatt peak

NASA: National Aeronautics and Space Administration

NEA: Nepal Electricity Authority

NDS: National Dasarath Stadium

NOC: Nepal Oil Corporation

NPC: National Planning Commission

NPV: Net Present Value

NRs: Nepalese Rupees

PEC: Power Exchange Committee

PPA: Power Purchase Agreement

PV: Photovoltaic

PVSYST: PV System Software

PR: Performance Ratio

ROE: Return on Equity

SAM: System Advisor Model

SDG: Sustainable Development Goals

STC: Standard Test Condition

SUPSI: University of Applied Sciences of Southern Switzerland

THD: Total Harmonic Distortion

USD: United States Dollar

VA: Volt Ampere

VGF: Variable Gap Funding

W : Watt

Wp: Watt peak

CHAPTER ONE: INTRODUCTION

1.1 Background

One of the key constraints of Nepal's development is energy crisis. The electricity load shedding caused serious impediment to growth but also a huge financial burden for households, industries, other businesses, and the government. More than 60 billion Nepalese rupees are being lost due to interrupted and irregular supply to the industrial sector alone (Pokharel, 2013). Although, Nepal is endorsed with very rich resource of hydropower, and its electricity supply being mainly hydro based, the crisis could not be fulfilled through internal supply. Recently, Nepal has been declared load shedding free zone after the door opened for massive import of electricity from the neighboring country India. This has caused irrelevant dependency upon the neighboring country for the management of electricity demand of Nepal. Furthermore, huge amount of money is flowing back to the India for the import as similar to the unutilized hydro resource flowing to the same. It has further imposed on trade deficit with neighboring country India. The data has revealed that Nepal has the highest trade deficit this year with the India.

The long-term solution for addressing the energy crisis is to sustainably develop its huge hydro resources. However, it will take years before the country's major hydro power plants are commissioned. To resolve the existing power crisis, options like utilization of other abundant renewable energy resources such as solar, biogas, wind, biomass, mini and micro hydro etc. should also be explored. This can also help enhance Nepal's energy security by diversifying its mix of primary energy sources.

A study shows that about 300,000 households in Kathmandu valley itself are using electrical backup systems to deal with long hours of load shedding (Nepal, 2014). The electrical backup systems use grid electricity to charge the batteries which increases the burden on national grid, and hence impose more pressure on the current supply system and exacerbates the already severe load shedding. People prefer electrical/battery backup systems (typical inverter & battery backup) because of lower investments cost than other backup sources. In this context, solar energy is a much more expensive alternative option for users. The initial capital investment for generating power with backup from solar energy is also higher compared to diesel generators and inverter-battery backup systems which is hindering the use of solar backup systems. Based on a survey sponsored by World Bank, the total installed captive capacity of diesel generator (DG) sets in Kathmandu valley is almost 200 MW(Nakarmi,2014). Diesel electricity is very costly and heavily polluting. But the commercial sector and business houses are forced to use diesel generators, considering that they need stable power to run their businesses. However, the recent technology development has lowered the price of such solar panel, inverter and battery backup systems. Thus, solar PV systems could be potentially an attractive alternative for DG sets or could be an important complement to the DG sets in reducing the costs of supply. In fact, the levelised costs of solar PV energy are already lower than DG costs, but other challenges may be constraining uptake. At present, in major cities of Nepal such as the Kathmandu Valley, rooftop solar PVs have not been broadly installed yet either by households or by commercial and industrial users due to non user friendly policy and unattractive subsidies from the government. Recently, doors have been opened up by the guidelines formulated by the Ministry of Energy for the net-metering of grid tied PV systems which allows owner of PV system to sell the excess energy generated to grid through net metering (MOE, 2017/18).

Historically, Nepal's power sector has been dominated by Nepal Electricity Authority (NEA), a Government owned utility. Currently, total installed electric power generating capacity is dominated by hydropower, which constitutes 93 percent of installed capacity. The balance is composed of thermal installations using 39 MW multi fuels and 14 MW diesel plants.

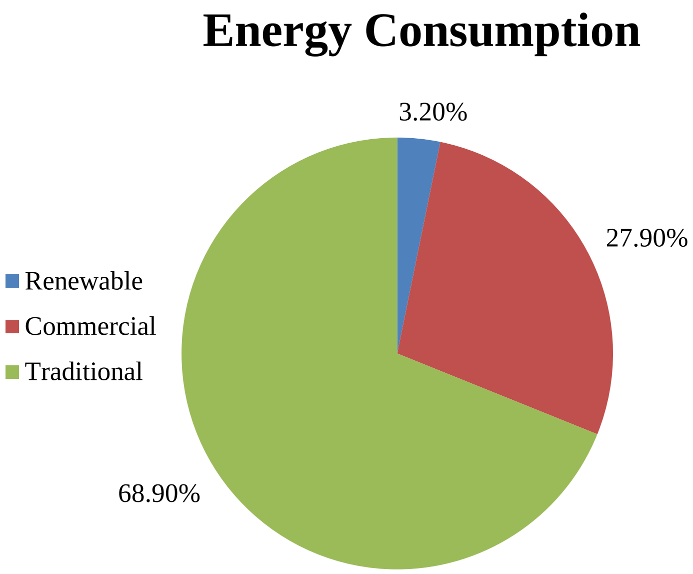


Figure 1.1: Status of Energy Consumption (Source: MOEWRI, 2017/2018)

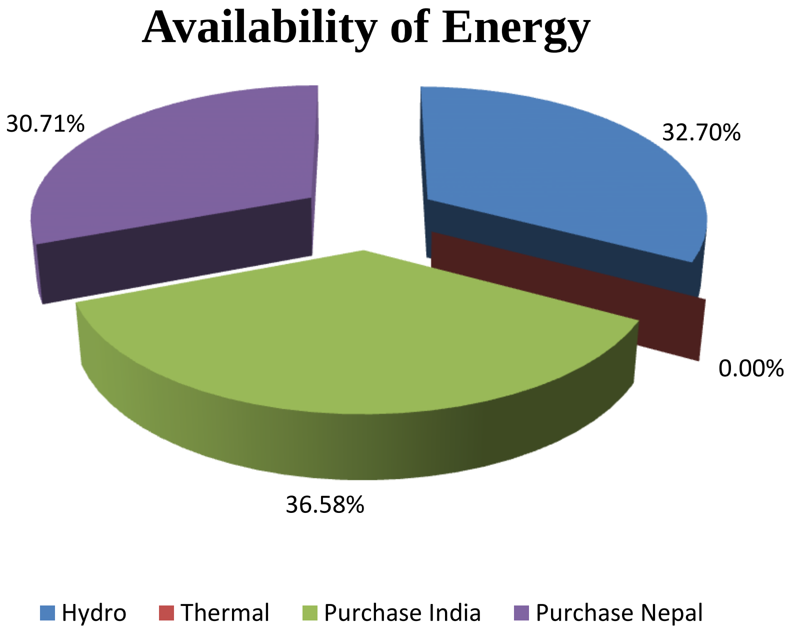


Figure 1.2: NEA, IPP, India involved in energy generation (Source: NEA, 2018)

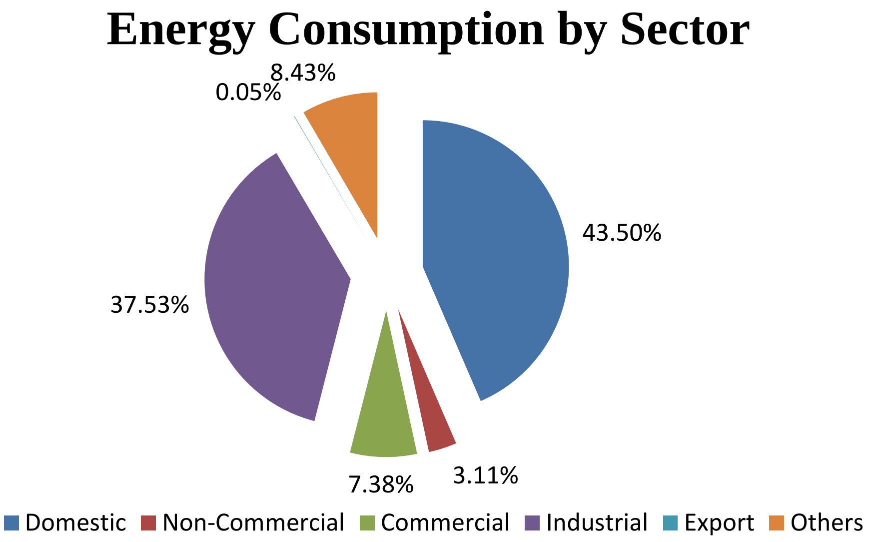


Figure 1.3: Energy Consumption by Sector (Source: NEA, 2018)

The chart below shows the total peak demand and total energy available of current system. There is a sharp difference between the total peak demand and energy available. This shows that there is severe energy crisis.

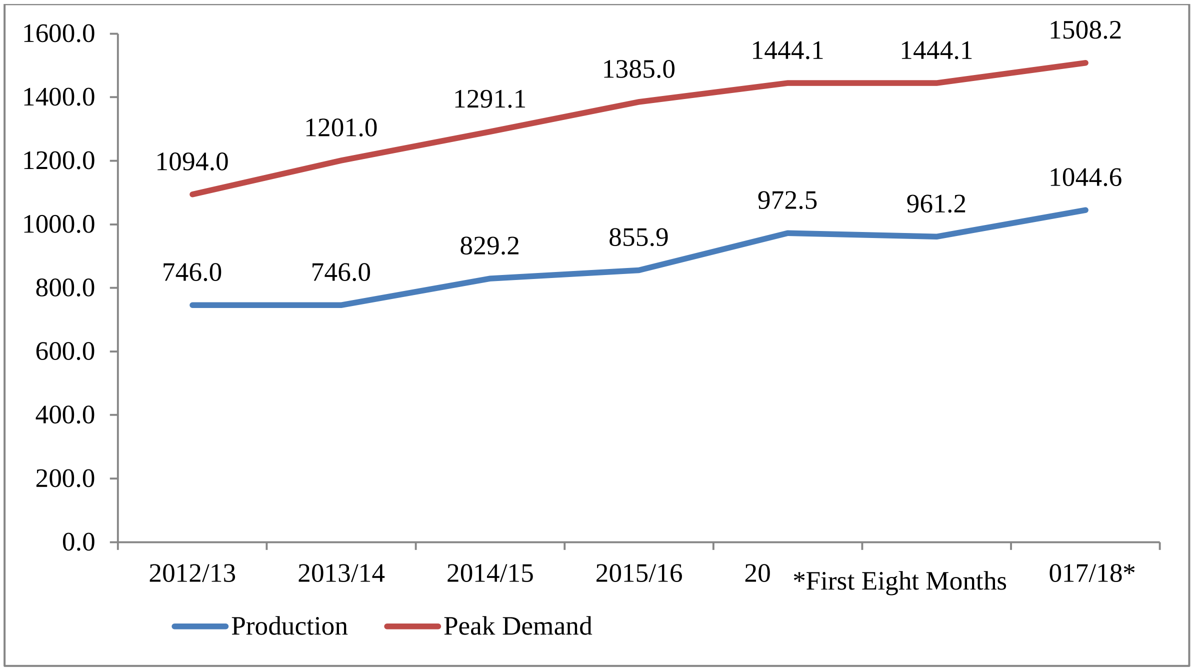


Figure 1.4: Total supply and peak demand (Source: MOEWRI, 2018)

Per capita electricity consumption of Nepalese is 195 units, far below the per capita electricity consumption of Asia which is 806 units as per the latest economic survey 2075 conducted by Ministry of Finance. There are many solutions to increase Energy availability; Apart from hydropower, eco-friendly green solar technology is good choice for quick energy generation; Out of which one is Utility solar PV grid tied system and other are Grid Tied Rooftop system. The system consists of solar panels and an inverter. The inverter supplies generated electricity from the PV modules to the grid. Nepal has on average more than double the solar insolation (kWh/m^2 day) than Germany -the world leader in solar PV installations. But in Nepal we lack appropriate law, policy, subsidy for grid tied rooftop revolution.

Huge Solar energy is incident over Nepal’s land area with most parts receiving 4-7 kWh per sq. m per day. The annual average global solar radiation on horizontal surface, incident over Nepal is about 4.7 kWh per square meter per day or 1650 kWh per sq. meter per year. There are about 300 clear sunny days in most parts of the country.

1.2 Benefits of grid tied solar rooftop with battery backup in residential sector

There are many advantages of PV electric system some of which are listed below:

- Safe, clean, renewable and quiet to operate, can be installed quickly.
- No cost in transmission line erection
- The solar energy can be stored in battery giving continuous supply of power even during power outage
- The electricity it produces is used where it’s needed: on-site or by the grid; meeting an immediate electricity need
- Use of maximum potential solar energy
- Minimization of large GHG emissions if compared to diesel plant
- Solar PV electricity generation would improve the voltage profile in the distribution lines, thereby reducing transmission and distribution losses.

1.3 The Concept of Net Metering

The concept of net metering involves recording the net energy between export of generated energy and import of energy from distribution licensee for a given period of time. This involves the usage of a bi-directional meter which has the facility to record both import and export values. Under the net metering system, the excess energy generated by the solar photovoltaic plant at a given point of time is exported to the grid. At the end of the billing period if more energy is exported to the grid than imported, then the distribution licensee pays the consumer at a pre-determined price. On the other hand if more energy is imported from the grid than exported, then the consumer pays the distribution licensee at a predetermined price.

1.4 Problem statement

Nepal is suffering from the lagging energy supply from year to year. It is difficult to meet the current and future demand without stimulating the energy vision. Loadshedding hours of 2069 was maximum in the history of Nepal with 18 hours which decreased to 13 hours in 2070 year and recent years there is no load shedding to the residential sector as energy deficit is fulfilled from India's supply as well as demand side management. We had experienced severe load shedding even at day when we had plenty of solar energy potential at our end due to lack of proactiveness from the Government of Nepal. The INPS of Nepal has been suffering frequent blackout due to improper protection coordination of transmission lines and insufficient spinning reserve capacity. Similarly, the distribution lines reliability is poor causing frequent interruption of the line. Thus, proper energy mix and use of renewable energy with backup source is must to solve the problem. The alternative source of energy from fossil fuel is expensive. To increase energy availability at a quick and cheaper rate, solar grid tied PV can be fruitful. But, during the power failure all the energy generation from grid tied PV goes to waste. Thus, to fulfill the demand from residential sector at quick rate, grid tied PV plant with backup battery source is the most probable and reliable solution. However, one of the major constraints of this system is high investment cost.

1.5 Objectives

Main Objectives

- To carry out techno-financial analysis of grid tied solar rooftop with battery backup on residential sector considering net metering at Star Homes, Sitapaila, Nepal

Specific Objectives

- To study load pattern of different types of houses of the housing sector.
- To design grid tied solar rooftop with and without battery backup for each type of Star homes considering load profile.
- To perform comparative analysis of the design with standalone system for a single type of house.
- To study the impact(including peak shaving, load management, load profile) of grid tied PV system with and without battery integration.
- To carry out the financial analysis of the grid tied solar rooftop considering net metering and tariff rate proposed by the government.

1.6 Assumption/ limitation

a) The surveyed load profile is assumed similar for similar type of houses. Thus, its average is used for the design. The load profile of similar house type was averaged assuming they have similar daily requirement.

b) Many people hesitated to answer the questions. Many people were unaware of technical terms. Thus, the reliability of surveyed data cannot be assured.

c) As the Nepal market is still unaware of the grid connected inverters accessories, lithium ion batteries, their cost shall be assumed from the international market without considering custom and transportation charges.

CHAPTER TWO: LITERATURE REVIEW

This chapter presents a literature review for a background understanding of INPS, the concepts of PV systems and its types. A short background to solar energy, its types, components, parameter and cost scenario of solar system is provided

2.1 Brief description of INPS:

Only 4 % of total energy required for Nepal is contributed by the electricity (International Energy Agency, 2016). The only government owned utility working in electricity sector is NEA. Out of the theoretical potentiality of 83290 MW in Nepal, only 1128 MW of hydropower has so far been developed (NEA, 2018/19). The installed capacity decreases to one third during the dry season. Similarly, the peak demand recorded is 1243 MW as per figure shown below which could not be fully met although huge energy was imported from India. The primary resource to power generation in the country is hydro-power but solar thermal, solar PV and thermal plants should also be considered for alternative options for reliable power supply and minimize import from neighboring country. Since thermal (diesel plant) are costly and non eco-friendly, it should not be emphasized without proper planning and vision.

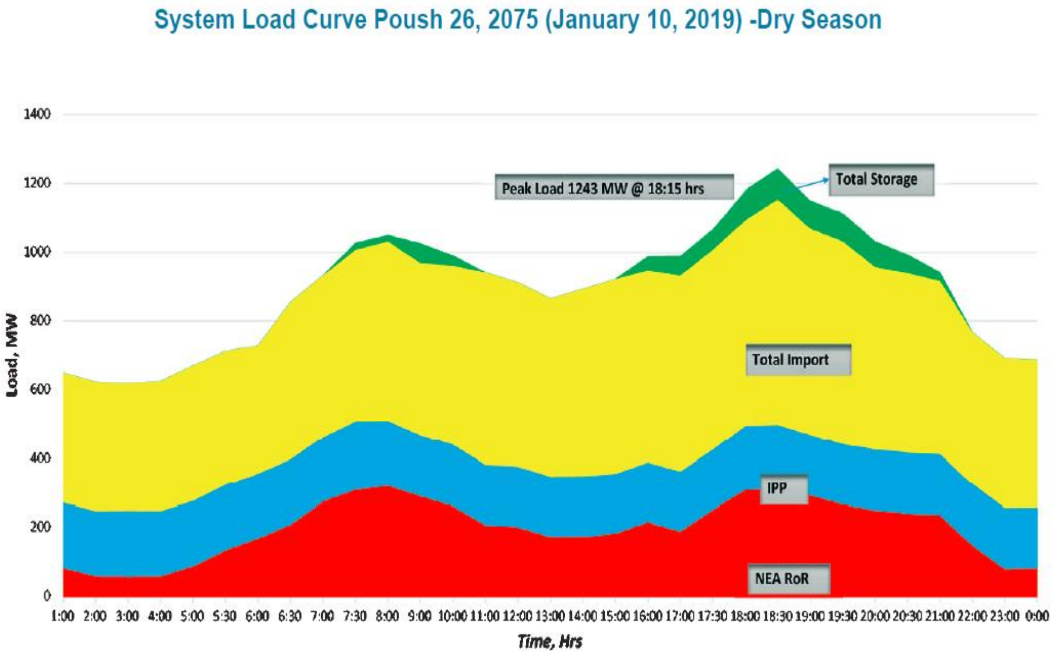


Figure 2.1: Total supply and Peak demand **(**Source: NEA, A Year In Review, 2018**)**

2.2 Cost of solar system

The cost of components of solar system such as inverter and solar panel has been drastically falling down. The recent study by NEA engineering company submitted to aspect of distributed generations with motive to prepare workable plan for sustainable distributed generation for grid access for all. For the base case of 1 MW ac grid tied solar plant with 500 kWh battery storage, the LCOE is at NRs. 11.96, 12.16, 12.56, 13.25, and 14.02 per kWh for region E, F, D, C, A and B respectively. Without VGF, the NEA PPA rate of NRs. 6/kWh with '8' simple escalations 3% each for 15% ROE would be around NRs. 14.85/ kWh. For the base case of alternative scenario in which 1 MWac solar plant without battery storage is considered, the LCOE of region A (east terai) decreases from NRs. 14.02 to NRs. 10.15 per kWh. Nonetheless, the VGF of NRs. 60,000/kWac is still necessary for ensuring 15% ROE. Without VGF, the NEA PPA rate of NRs. 6/kWh with '8' simple escalations 3% escalations each required for 15% ROE would be around NRs. 10.79/ kWh.(NEAEC, 2019)

2.3 Power exchange scenario of Nepal:

Nepal has a peak demand during winter while India has a peak during summer. Two countries therefore have mutual interests in power exchange.

Nepal imports power from India at 220kV level from Mujjafarpur, 132 kV voltage level from Tanakpur (India) to Mahendranagar (Nepal) in the far west and from Kataiya (India) to Duhabi (Nepal) in the East. Nepal imports as well as exports power to India at 132 kV voltage level from Gandak (Nepal) to Ramnagar (India). Nepal is also entitled to receive 70 GWh energy free annually from Tanakpur in the far west under the Mahakali Treaty and 10 MW power according to the Koshi contract.

The eleventh (Power Exchange Committee) PEC meeting fixed the tariff structure as shown in the table. The quantum of the corresponding energy import under this power exchange mode reached 1507.39 GWh corresponding to NRs.13,190.98 million in total.

Table 2.1: Tariff of import **(**Source: NEA, 2018)

Year	Tariff for System Voltage(IRs)			
	132 kV	33 kV	11 kV	Koshi Supply
2017	5.55	6.00	6.45	2.83

The power trading signed between the Power Purchase Agreement on 28th March, 2018 between NEA and NTPC Viduyt Vyapar Nigam (NVVN), the nodal agency of the government of the India for dealing with power trading issues with Nepal. The quantum of power agreed was up to 120 MW to be transmitted to Nepal through Dhalkebar – Mujaffarpur Cross Border Transmission Line for the period of 15 months effective from April 1, 2018 and corresponding tariffs agreed were IRs. 3.98 per kWh for the first sixth months and IRs.4.18/kWh for the remaining nine months. The quantum of the corresponding energy import under this power trading mode reached 883.49 GWh corresponding to NRs. 5,195.55 million in total. Nepal also imported power through Tanakpur at IRs. 3.44 per kWh under the Power Purchase Agreement with PTC India Limited for some months of the dry season and the quantum of the corresponding energy import under this power trading mode reached 120.9 GWh corresponding to NRs. 652.73 million in total. Two new 132 kV Transmission lines, Kataiya- Kushaha II and Raxaul-Parwanipur, were commissioned and commercial arrangement for drawing power of 50 MW from each of them through North Bihar Power Distribution Company Limited was made. Maximum power import from India in peak hours reached 521 MW in April/May, 2018, whereas the highest average power withdrawal recorded was 425 MW in January/February, 2018. The total quantum of energy transaction with a rise of 18.7 % reached to 2,581.78 GWh including 70 million units under the Mahakali Treaty. This corresponded to a payment of NRs. 19,371.76 million in the fiscal year 2017/18 against NRs 16,051.31 million for 2,175.04 GWh in the year 2016/17.(NEA,2018)

2.4 Earlier Works:

It is important to state that the amount of literature on the solar energy system and PV grid connected system is enormous. The Grid connected rooftop solar with battery backup has been studied and implemented successfully in many countries specially developed countries like Germany, Japan, Italy etc. In context of Nepal Solar Home Systems (SHS) are very common in rural and urban Nepal. Many companies are installing standalone systems all over the country, particularly in rural areas. The Alternative Energy Promotion Centre (AEPC) organizes training courses on stand-alone systems, but solar PV companies do not have the knowledge or skilled professionals required in order to design, install and maintain grid-connected solar PV systems or mini-grid systems.

Several works are going on solar photo voltaic systems. Some of these are discuss below.

- Tazvinga et al. (2015) presented paper on “Demand side management of photovoltaic –battery hybrid system”. Paper concludes an example of Demand Response program, time of use with power selling over peak period, has been studied for energy management. It can be observed that the battery plays a significant role in storing grid power during off-peak periods and supplying power to customers during peak periods. As a result, by scheduling the hybrid system, customers consume minimal amount of power from the grid and reduce their monthly cost.
- Shrestha (2014) presented paper on “Impact of Small Decentralized PV Grid - Connected Plants on Load Shedding in Nepal.” Paper concludes five 1.1kWp PV grid-connected systems were installed in the Kathmandu urban area. The plant situated in RIDS, Imadol is not connected to the grid (no NEA permission) but the storage system makes it possible to increase overall performance by up to 61.6%.
- White Paper (2013) “Rooftop Solar and Net Metering in India - A Detailed Analysis.” The purpose of this document was to give Solar PV system integrators, companies looking to enter the rooftop solar market and potential customers a low down on the policies and where the market is heading
- Khalil (2012) presented “Design and Simulation of a Grid-Connected Photovoltaic System for the EE Department Building in Assiut University.” This paper presents the complete design of a grid-connected Photovoltaic (PV) system to supply electric power for the Department of Electrical Engineering in Assiut University, Assiut Province, Egypt according to their energy requirements. This system can be

installed on the roof and the south side of the Department of Electrical Engineering. Homer software is used as the sizing and optimization tool to determine the size and specifications of photovoltaic system components, system cost and estimation of corresponding produced electrical power

The following are the few research thesis that I referenced for the research gap. According to my analysis there has been no any work regarding grid tied solar in residential sector.

Author/Title	Conclusion	Limitation
Bhattarai (2013) Performance Analysis of One kilowatt Grid Connected Solar Photovoltaic (PV) Electric System.	The analysis of data indicates that the average final yield was 2.31 kWh/day; array yield was 2.64 kWh/day and performance ratio of 0.488 under the normal load shedding condition. The per unit cost of electricity was found to be NRs 16.63.	There was no battery backup in the system. During load shedding hours the solar energy could not be used.
Shrestha (2014) Techno–Economic Analysis of a Utility Scale Photovoltaic Plant (A Case Study of One MWp Plant at Trishuli)	The unused land has a potential of 58 MWp of utility scale PV plant. This study also presents a design of a one MWp utility scale PV plant at the premises of Trishuli Hydropower Station. Economic analysis of the plant at the tariff rate of NRs 10.5 per unit, the plant has a positive net present value of NRs 23,277,818.	Grid impact study needs to be performed due to injection of power from the PV plant and its effect on INPS. There is no use of battery backup in the system
Chettri (2015) Prototype Net Zero Energy Contemporary Residential Building	Through use of energy efficient techniques we can save around 33% of annual electricity consumption of the household. Solar panel of	Detail analysis of Solar PV has not been done in residential sector. Financial

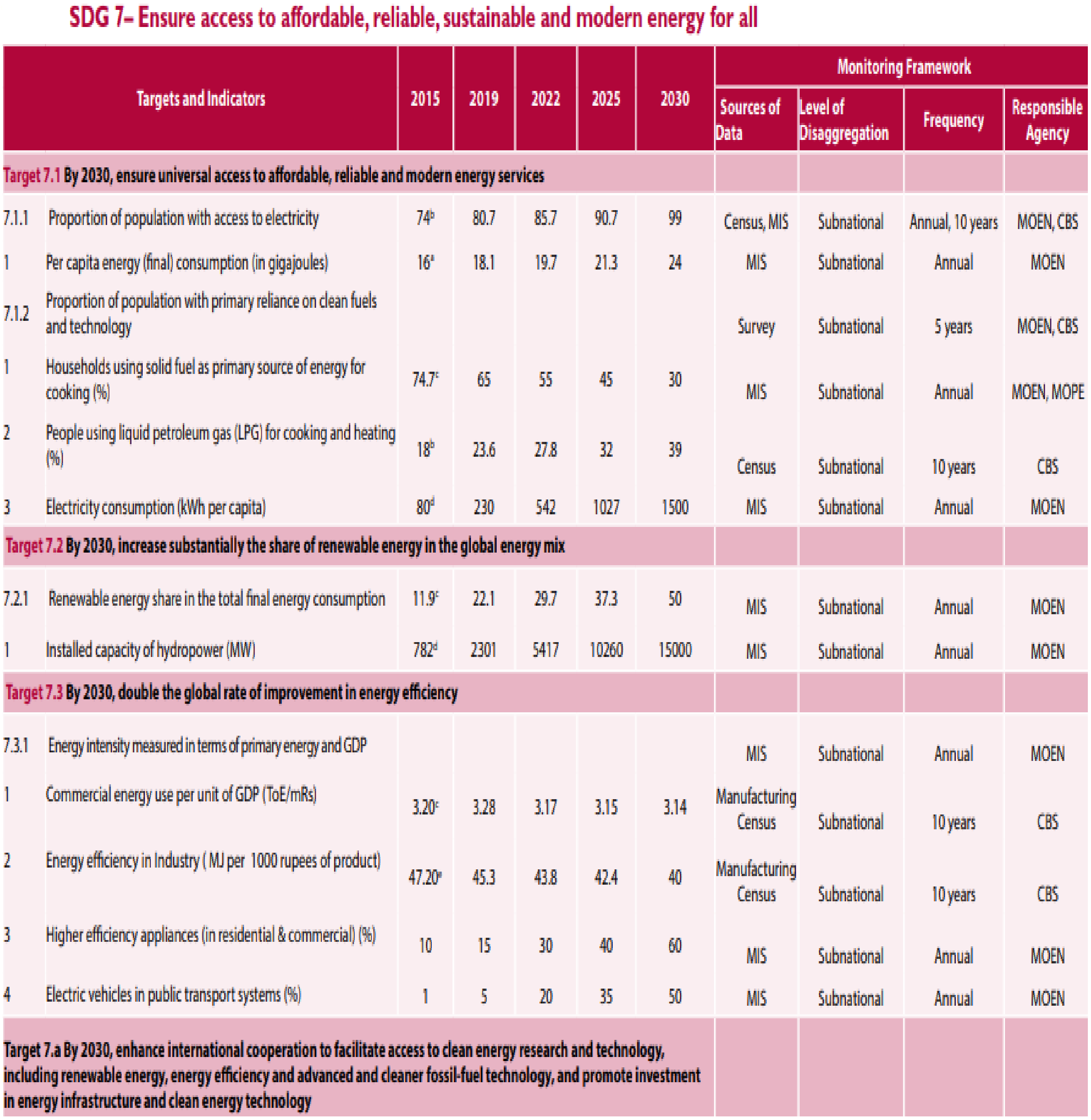
for Kathmandu Valley	capacity 1512 kWh per year is installed to make typical net zero energy building	analysis of solar PV has not been done
Shakya (2015) Case Study On Grid Integrated Solar PV For National Dasarath Stadium	This study presents a design of a grid tied 998.4 kWp utility scale PV plant at the premises of National Dasarath Stadium. The designed plant is found to be both technically and economically viable. Comparative analysis of Solar PV and Diesel Genset.	Further study can be done at other Stadium, Bigger apartments, Malls, department stores.
Aryal(2017) Performance Analysis of Solar PV System of Teaching Hospital, Kathmandu, Nepal	The study presents 115 kWp solar PV plant installed at Teaching Hospital. The performance ratio was 17.41%, capacity utilization factor 3.52% and specific yield was 304.25 kWh per kWp per year and annual energy generation of 34.99 MWh. However, the PVSYST simulation results shows higher specific yield 1728 kWh/kWp/year and higher performance ratio of 83.48%.	The difference in these values is not properly justified. Only 28 kWp load in is connected to the system, and energy is not injected to the grid, the system produces power only to feed the load and charge the battery.

2.5 PV system in Nepal:

In rural households without grid infrastructure, PV electricity is very popular. Many organizations working for rural development have utilized PV application to uplift their standard of life. The Grid connection of PV power has just been beginning. 680.4 kW grid tied plant in Sudarighat funded by JICA have been operation successfully. NEA has also installed 100 kW of grid tied solar in Kharipati and is planning to install 25 MW of grid tied solar in Trishuli. Water pumping from solar PV is also popular at different location without grid facility. Standalone solar homes systems of small sizes such as 5 Wp to 50 Wp are popular in urban area. While rich people install above than 50 Wp in their house to lighten up during the load shedding. Highest utilization of PV energy in Nepal is done by telecommunication sector.

Similarly, as per sustainable development goal of Nepal following target has been set to increase renewable energy mix and increase affordability, reliability, sustainability and modern energy for all.

Table 2.2: Ensure access to affordable, reliable, sustainable and modern energy for all (NPC, 2015)

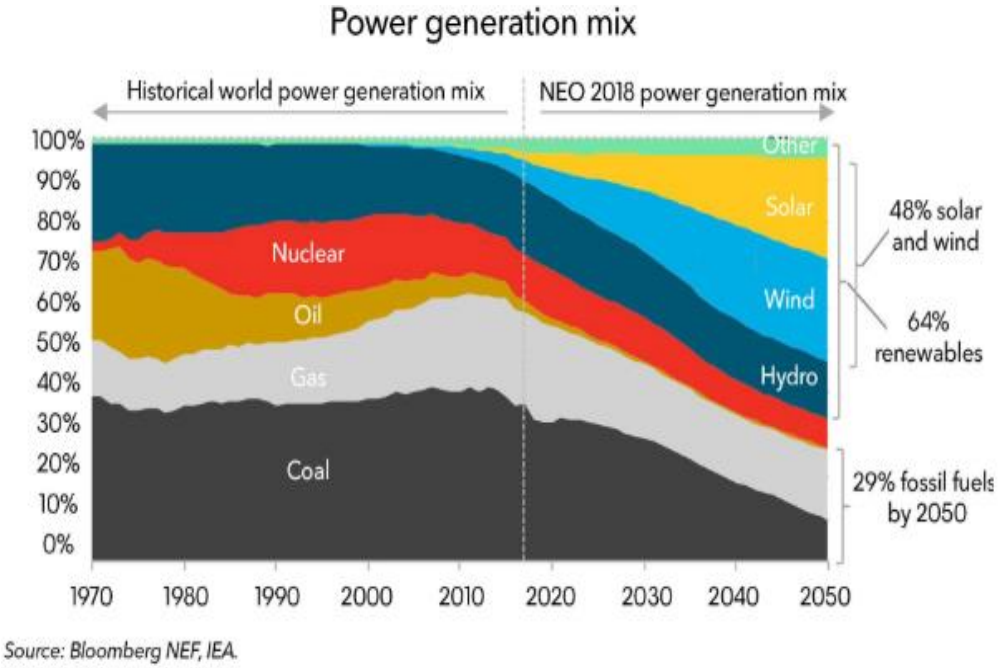


SDG 7– Ensure access to affordable, reliable, sustainable and modern energy for all

Targets and Indicators		2015	2019	2022	2025	2030	Monitoring Framework			
							Sources of Data	Level of Disaggregation	Frequency	Responsible Agency
Target 7.1 By 2030, ensure universal access to affordable, reliable and modern energy services										
7.1.1	Proportion of population with access to electricity	74[b]	80.7	85.7	90.7	99	Census, MIS	Subnational	Annual, 10 years	MOEN, CBS
1	Per capita energy (final) consumption (in gigajoules)	16[a]	18.1	19.7	21.3	24	MIS	Subnational	Annual	MOEN
7.1.2	Proportion of population with primary reliance on clean fuels and technology						Survey	Subnational	5 years	MOEN, CBS
1	Households using solid fuel as primary source of energy for cooking (%)	74.7[c]	65	55	45	30	MIS	Subnational	Annual	MOEN, MOPE
2	People using liquid petroleum gas (LPG) for cooking and heating (%)	18[b]	23.6	27.8	32	39	Census	Subnational	10 years	CBS
3	Electricity consumption (kWh per capita)	80[d]	230	542	1027	1500	MIS	Subnational	Annual	MOEN
Target 7.2 By 2030, increase substantially the share of renewable energy in the global energy mix										
7.2.1	Renewable energy share in the total final energy consumption	11.9[c]	22.1	29.7	37.3	50	MIS	Subnational	Annual	MOEN
1	Installed capacity of hydropower (MW)	782[d]	2301	5417	10260	15000	MIS	Subnational	Annual	MOEN
Target 7.3 By 2030, double the global rate of improvement in energy efficiency										
7.3.1	Energy intensity measured in terms of primary energy and GDP						MIS	Subnational	Annual	MOEN
1	Commercial energy use per unit of GDP (ToE/mRs)	3.20[c]	3.28	3.17	3.15	3.14	Manufacturing Census	Subnational	10 years	CBS
2	Energy efficiency in Industry (MJ per 1000 rupees of product)	47.20[e]	45.3	43.8	42.4	40	Manufacturing Census	Subnational	10 years	CBS
3	Higher efficiency appliances (in residential & commercial) (%)	10	15	30	40	60	MIS	Subnational	Annual	MOEN
4	Electric vehicles in public transport systems (%)	1	5	20	35	50	MIS	Subnational	Annual	MOEN
Target 7.a By 2030, enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology										

2.6 Grid tied PV system in World and Cost comparison

One hundred thirty seven (137) GWp of total PV system has been installed in the world by December 2013. More than 80% of 137 GWp has been connected to the utility grid. Top five largest PV plants in world are as follows: 1. Topaz Solar Farm in USA — 550 MW (300 MW completed up through January 2014) 2. Agua Caliente in USA — 251 MW (397 MW when complete) 3. California Valley Solar Ranch in USA — 250 MW (completed in 2013) 4.Antelope Valley Solar Ranch in USA — 230 MW (almost complete) 5. Charanka Solar Park in China — 221 MW. In 2005, the global installed capacity of Solar PV was 5.1 GW; however, by 2016 this capacity had increased about 40 times to 303 GW, of which 75 GW was added only last year. According to market forecasts, the installed PV power capacity of 408 GW at the end of 2017 could triple by 2023. At the end of 2018, worldwide solar PV power is expected to exceed 500 GW capable of producing roughly 2.8 % of the worldwide electricity demand. Out of the total global capacity, China alone accounts for around 78 GW, followed by Japan which accounts for 43 GW. With more than 40 times increase in global solar PV capacity over just a decade, Solar PV technology is the fastest growing technology among all the renewable energy technologies.



Source: Bloomberg NEF, IEA.

Figure 2.2: Power Generation Mix(Source: Bloomberg, 2018)

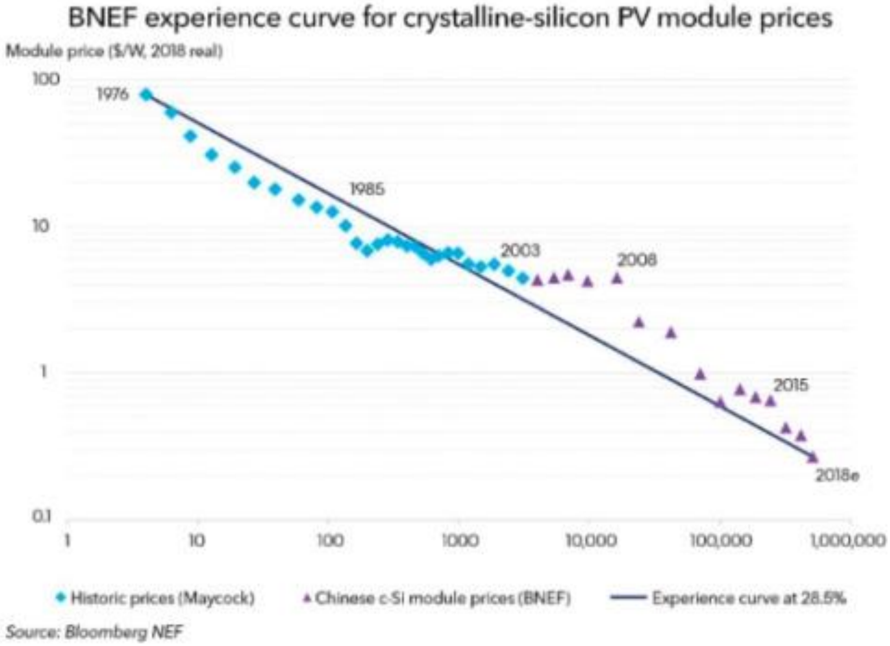


Figure 2.3: Price Comparison of Solar PV over time period(Source: Bloomberg, 2018)

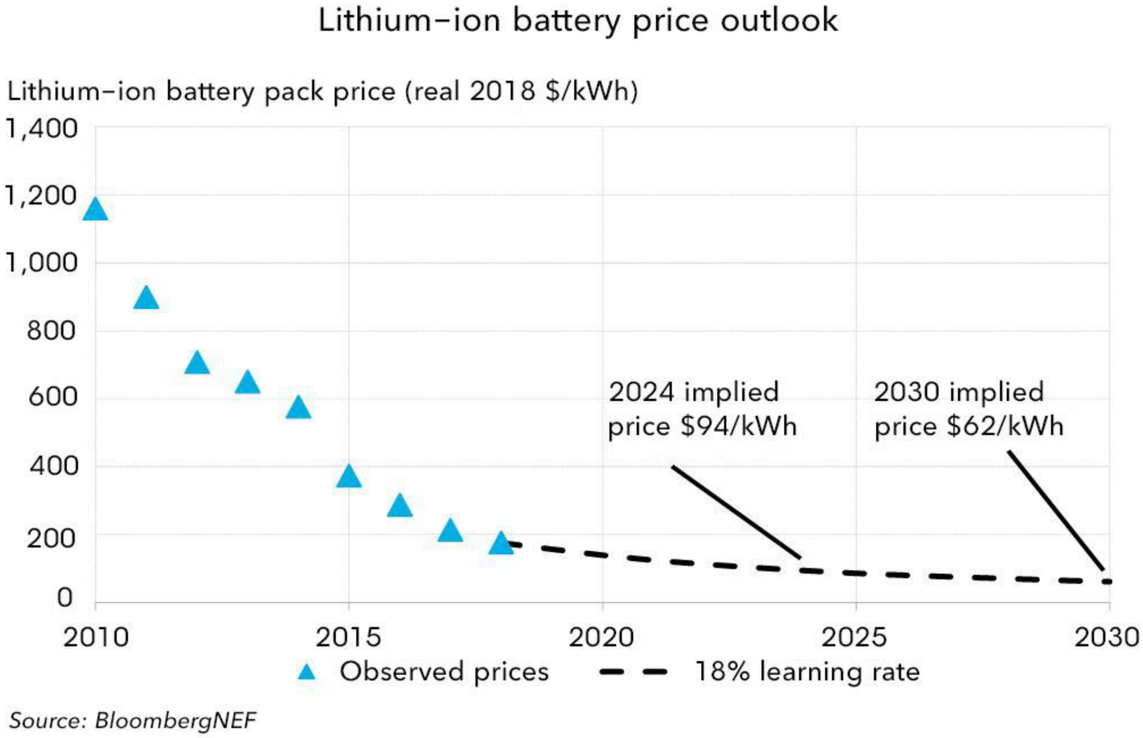


Figure 2.4: Price Comparison of Lithium Ion Batteries over time period (Source: Bloomberg, 2018)

2.7 About solar PV technology

There are four primary applications for PV power systems:

- Off-grid domestic – Provides electricity to households and villages that are not connected to the utility electricity network (the ―grid‖).
- Off-grid non-domestic – Provides electricity for a wide range of applications such as telecommunication, water pumping and navigational aids.
- Grid-connected distributed PV – Provides electricity to grid-connected customer.
- Grid-connected centralized PV – Provides centralized power generation for the supply of bulk power into the grid.

2.7.1 Grid tied battery backup system components

The main components include:

- Solar PV modules – These convert solar radiation directly into electricity through the photovoltaic effect. The photovoltaic effect is a semiconductor effect whereby solar radiation falling onto the semiconductor PV cells generates electron movement. The output from a solar PV cell is direct current (DC) electricity
- Module mounting (or tracking) systems – These allow PV modules to be securely attached to the ground at a fixed tilt angle, or on sun-tracking frames.
- Inverters – These are required to convert the DC electricity to alternating current (AC) for connection to the utility grid. Many modules in series strings and parallel strings are connected to the inverters.
- Battery –A battery converts between chemical and electrical energy. The main functionality of a battery in a PV system is to store excess energy to use during the hours when no energy is produced. This storage technology allows more renewable integration into the grid. PV production is highly dependent on the weather profile, like many other renewable sources and these uncertain power fluctuations create stress on the grid. Battery storage can act as an energy buffer in between generation and load. The services such as peak shaving, load leveling, frequency and voltage control for grid stability can be provided from battery storage for transmission and distribution.
- Meters: They account for the energy being drawn from or fed into the utility network.

Modules

- Crystalline Silicon (c-Si) – Modules are made from cells of either mono-crystalline or multi-crystalline silicon. Mono-crystalline silicon cells are generally the most efficient, but are also more costly than multi-crystalline.
- Thin Film – Modules are made with a thin film deposition of a semiconductor onto a substrate. This class includes semiconductors made from: Amorphous silicon (a-Si), Cadmium telluride, Copper indium selenide, Copper indium (gallium) di-selenide.
- Heterojunction with intrinsic thin-film layer (HIT) – Modules are composed of a mono-thin c-Si wafer surrounded by ultra-thin a-Si layers.

Table 2.3: Comparison of different cell technology(IFC, 2015)

Cell Material	Module Efficiency
Heterojunction with intrinsic thin film layer(HIT)	18-20%
Crystalline Silicon(c-Si)	13-21%
Thin film Copper Indium Gallium Di-Selenide(CIGS or CIS)	8-14%
Thin film Cadmium Telluride(CdTe)	8-16%
Amorphous Silicon a-Si	6-9%

Mounting and tracking Systems

PV modules must be mounted on a structure, to keep them oriented in the correct direction and to provide them with structural support and protection. Mounting structures maybe fixed or tracking. Fixed mounting systems keep the rows of modules at a fixed tilt angle while facing a fixed angle of orientation. Fixed tilt mounting systems are simpler, cheaper and have lower maintenance requirements than tracking systems. They are the preferred option for countries with a nascent solar market and limited indigenous manufacturing of tracking technology. Depending on the site and precise characteristics of the solar irradiation, trackers may increase the annual energy yield by up to 26% for single-axis and 35% for dual-axis trackers. Tracking also produces a smoother power output plateau.

Inverters

Inverters are solid state electronic devices. They convert DC electricity generated by the PV modules into AC electricity, ideally conforming to the local grid requirements. Inverters can perform variety of functions to maximize the output of the plant. These range from optimizing the voltage across the strings and monitoring string performance to logging data and providing protection and isolation in case of irregularities in the grid or with the PV modules.

Inverter connection concepts

There are two broad classes of inverters: central inverters and string inverters. In central inverter, a large number of modules are connected in series to form a high voltage string. Strings are then connected in parallel to the inverter. Central inverters offer high reliability and simplicity of installation. However, they have disadvantages: increased mismatch losses and absence of maximum power point tracking (MPPT) for each string. This may cause problems for arrays that have multiple tilt and orientation angles, suffer from shading, or use different module types. Central inverters are usually three-phase and can include grid frequency transformers. These transformers increase the weight and volume of the inverters although they provide galvanic isolation from the grid. In other words, there is no electrical connection between the input and output voltages—a condition that is sometimes required by national electrical safety regulations. Transformer less inverters generally has a higher efficiency, as they do not include transformer losses.

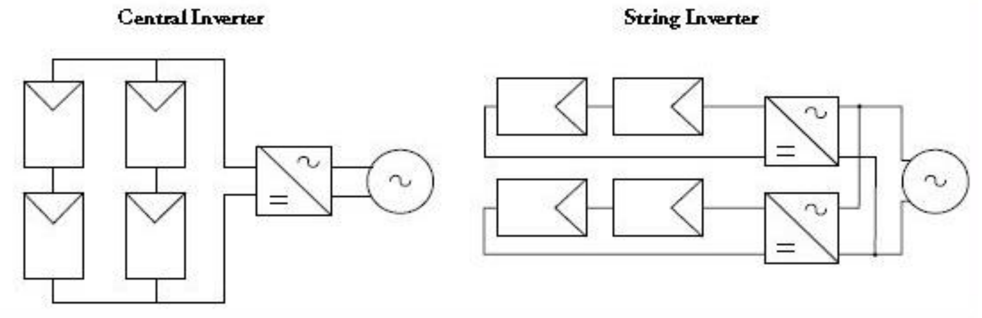


Figure 2.5: Central vs. String inverter[IFC, 2015]

Table 2.4: Comparison of Inverter connection concepts[IFC, 2015]

SN	String Inverter	Central Inverter
1.	Flexible Design, Single phase and 3 phase	Three phases inverter for design
2.	Shadowing effects easy to be minimized	Shadow effects no minimization
3.	No transmission Station required Quick installation behind modules	Transmission station required
4.	Hundreds of inverter ,complex installation and higher installation cost	Lower Installation cost
5.	Low inverter prices due to high volume manufacturing	Higher prices due to low manufacturing
6.	String monitoring included	String monitoring in addition
7.	No additional junction box required	Generation junction box in addition
8.	Smaller DC losses	Higher DC losses
9.	A lot of MPP tracker	Only several MPP tracker

Legal characteristics of inverter: (SUPSI)

1. Synchronous operation with the grid
2. Islanding prevention
3. Limitation of the output voltage (min & max).
4. Limits of the grid frequency (49Hz < f < 51Hz, depending on the country)
5. Low phase displacement (pf= 1).
6. Low levels of harmonics. (≤ 3 % distortion).
7. Electromagnetic compatibility (EMC).

Power quality/Grid Code compliance

Power quality and grid code requirements are country dependent. The national regulations and standards should be consulted when selecting an inverter and designing a solar PV power plant. In general, one of the quantities used to describe the quality of a grid-connected inverter is Total Harmonic Distortion (THD). It is a measure of the harmonic content of the inverter output and must be limited in most grid codes. For high quality devices, THD is normally less than 5%.Voltage flicker also must be minimum. Power factor must be close to unity. Response time must be extremely fast. Islanding is the phenomena of shutting down the inverter on grid outage. It is necessary condition for grid integration of solar energy. IEC anti islanding standard has been developed which gives a time response of 2 seconds. Main methods for detecting undesired islanding

Passive methods (monitoring key grid parameters):

– Grid voltage monitoring (inverter shuts down in the presence of a voltage surge or low voltage).

– Frequency monitoring (inverter shuts down if the frequency is out of tolerance).

– Harmonics monitoring (inverter shuts down if harmonics are unduly high).

– Inverter shuts down if any of the aforementioned parameters changes abruptly.

– Inverter shuts down if the size of the phase angle between V and I increases abruptly

Active methods:

– Active frequency shift when the inverter is not connected to the grid and inverter shutdown if the tolerance limit is reached.

– Output power adjustment for active and/or reactive power.

– Grid impedance measurement and inverter shutdown if this parameter is unduly high.

Performance ratio

Performance ratio (PR) is the factor through which you can assess the plant performance, how the plant is behaving. If a plant has a performance ratio of 80%, it shows that 20% energy generated through the PV panels is lost in the system losses.

There are two basic parameters to calculate the performance ratio Y_f (Final PV system yield) and Y_r (Reference yield). PR is the Ratio of Y_f and Y_r.

Performance ratio = Y_f/Y_r

Where: $Y_f = E/P_o$ and E = Net energy Output in kWh

P_o = Installed PV array in kW

$Y_r = H/G$ and H = Total plane irradiance in kWh/m^2

G = PV reference irradiance in kW/m^2

Capacity factor

The capacity factor of a PV power plant (usually expressed as a percentage) is the ratio of the actual output over a period of one year and its output if it had operated at nominal power the entire year, as described by the formula:

$$\mathrm{CF}=\frac{(\text{Energy generated per annum (kWh)})}{(8760(\text{hours / annum})\times\text{Installed Capacity (kWp)})}$$

The capacity factor of a fixed tilt PV plant in Nepal will typically be in the region of 20%. This means that a 5 MWp plant will generate the equivalent energy of a continuously operating 1 MW plant.

Specific yield

The specific yield (kWh/kWp) is the total annual energy generated with per kWp installed. It is often used to determine the financial value of an array and compare operating results from different technologies and systems.

Quantifying the solar resource

Site selection and planning of PV power plants requires reliable solar resource data. Power production depends linearly on the plane of array irradiance, at least to a first approximation. The solar resource of a location is usually defined by the values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation as defined below.

- Global Horizontal Irradiation (GHI) – GHI is the total solar energy received on a unit area of horizontal surface. It includes energy from the sun that is received in a direct beam and from all directions of the sky when radiation is scattered off the atmosphere (diffuse irradiation). The yearly sum of the GHI is of particular relevance for PV power plants, which are able to make use of both the diffuse and beam components of solar irradiance.
- Direct Normal Irradiation (DNI) – DNI is the total solar energy received on a unit area of surface directly facing the sun at all times. The DNI is of particular interest for solar installations that track the sun and for concentrating solar technologies (as concentrating technologies can only make use of the direct component of irradiation).

- Diffuse Horizontal Irradiation (DHI) – DHI is the energy received on a unit area of horizontal surface from all directions when radiation is scattered off the atmosphere or surrounding area. A high long term average annual GHI is typically of most interest to PV project developers. Average monthly values are important when assessing the proportion of energy generated in each month.

Satellite derived data

Satellite-derived data can offer a wide geographical coverage and can often be obtained retrospectively for historical periods in which no ground-based measurements were taken. This is especially useful for assessing long term averages. Advantage of satellite resource assessment is that data is not susceptible to maintenance and calibration discontinuities. The same sensor is used to assess locations over a wide area. A comparison of the GHI values shows that statistics obtained from satellite readings correspond well with ground-measured data. But it is not so in the case of DNI values. Currently, it is not so clear if this dissonance is due to the satellite methodology or the poor maintenance of ground-based measurement stations, but is likely to be a combination of both. NASA uses satellite for the analysis.

Land based measurement

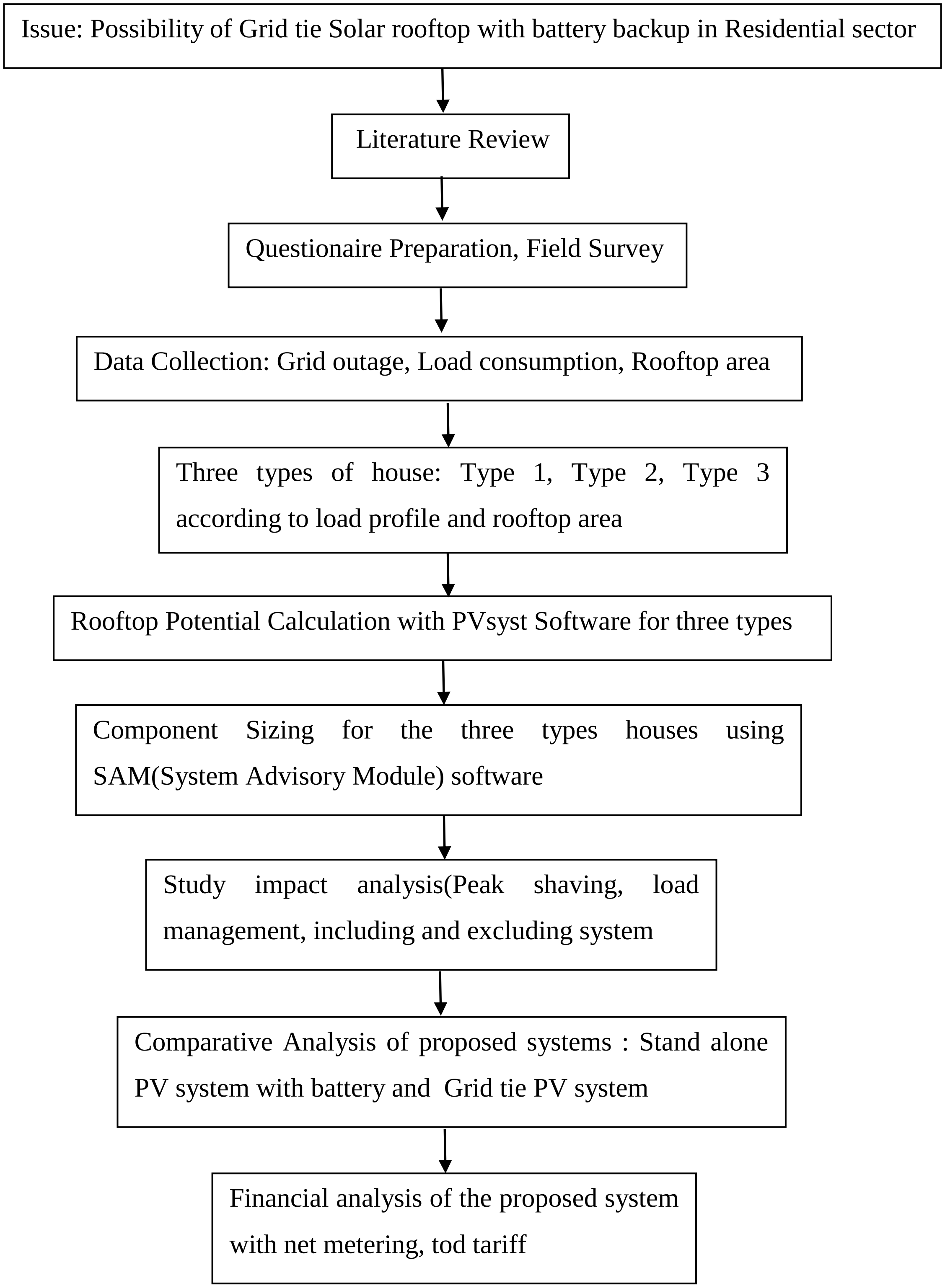
The traditional approach to solar resource measurement is to use land-based sensors. A variety of sensor technologies is available from a number of manufacturers with differing accuracy and cost implications. The two main technology classes are:

- Thermal Pyranometers – These are also known assolarimeters and typically consist of a black metal plate absorber surface below two hemispherical glass domes in white metal housing.

- Silicon Sensors – These are cheaper than pyranometers and consist of a PV cell, often using crystalline silicon. The current delivered is proportional to the irradiance. Temperature compensation can be used to increase accuracy but its scope is limited by the spectral sensitivity of the cell. compared to thermal pyranometers. Well maintained land-based sensors can measure the solar resource with a relative accuracy of 3-5%.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Method



This thesis is focused on the residential sector (taking one example of residential business group, star homes with 51 buildings in this thesis) of the nation whose demand is highest among all other sectors (industrial, commercial etc.). The data required for the research work was collected at different levels. Climatic conditions, meteorological data, market conditions, national electricity grid conditions, national electricity tariff rates, available subsidy policy, domestic/residential user's survey data was obtained from relevant places. A survey on group of residential users of star homes (middle-upper class families) has been carried out in order to focus on category of potential users of PV grid connected system with battery backup through interview with the questionnaires prepared for the survey. The demand load data stored in TOD meter of overall star homes with fifty three buildings was obtained from the relevant department. From the data stored in the meter, the reliability (grid outage) of local distribution grid was also analyzed. Manual dimension measurement was carried out in order to calculate the usable rooftop area and the solar potential of rooftop area was calculated using the area of the solar panel and its consecutive power.

During the field survey, twenty households out of 51 households provided the time and data as required while some house owners abstained from the questionnaire. As per the survey conducted, there were two households from type 1, fifteen households from type 2 and three households from type 3. Basically, the load profile of the Weekend and Weekdays were collected and projected for a week for all households. The load profile data was graphed for all surveyed households. The load profile for households with type 1, type 2 and type 3 was found similar in nature. Similarly, the electrical fittings, apparatus, size of house of same type are similar. Thus, one of the type 1 household, type 2 household and type 3 household load profile was selected for the necessary design and implementation considering three cases i.e with Standalone system, Grid connected PV system and Grid interactive PV system with backup. The components sizing of the solar system was done using calculations in MS-EXCEL Software for all three type and three cases. All cases were studied and analyzed through available software. For the standalone systems, PVSYST software was used for the simulation and for the rest systems i.e PV grid tie system and PV grid tie with backup, System Advisor Model(SAM) software was used. Moreover, peak shaving is also analyzed by the use of backup system in the SAM software and its result was presented on how grid is relieved from the load demand during the peak time. For all three cases, financial analysis is carried out considering net metering. Similarly, different scenario with different perspective i.e different discount rate, loan rate is considered during the analysis.

3.2 Research Tool

The components sizing of the solar system was done using calculations in MS-EXCEL. For the standalone systems, PVSYST software was used for the simulation and for the PV grid tie system and PV grid tie with backup, System Advisor Model(SAM) software.

3.3 Sampling method

There are various formulas for calculating the required sample size based upon whether the data collected is to be of a categorical or quantitative nature (e.g. is to estimate a proportion or a mean). These formulas require knowledge of the variance or proportion in the population and a determination as to the maximum desirable error, as well as the acceptable Type I error risk (e.g., confidence level). Since there is an inverse relationship between sample size and the Margin of Error, smaller sample sizes will yield larger Margins of Error. The formula used for these calculations was:

Sample size (n) =$(\chi^2 * N*(1-P))/(ME^2 ((N-1) + \chi^2 *P*(1-P)))$

(Source: Krejcie and Morgan (1970))

Where, n = required sample size

χ^2= Chi square for the specified confidence level at 1 degree of freedom

N= Population size

ME = Desired Marginal error (expressed as a proportion)

Confidence Interval	90%
Degree of Accuracy	0.15
Population Size	51
Sample Size	19.61~20

CHAPTER FOUR: RESULT AND DISCUSSIONS

Figure 4.1: Top view of Star Homes, Sitapaila(Google Earth Pro)

4.1 Categories of houses

The location of housing is 27°42'29.35"N latitude and 85°16'49.56"E longitude. Housing has 51 numbers of buildings. The houses are categorized according to the rooftop area and load as shown in the table.

Table 4.1: House type categorization

S.N	Type	Size	Roftop Area(m^2)	Load (VA)
1	Type 1	Small	<= 60	<2000
2	Type 2	Medium	60-150	2000-4500
3	Type 3	Big	>=150	>4500

The number of houses sampled according to the types of the houses using the sampling method is in the given table.

Table 4.2: Number of samples taken

S.N	Type	Number	Samples
1	Type 1	4	2
2	Type 2	43	15
3	Type 3	4	3

4.2 Backup sources being used

There were not any houses that use diesel generator sets as backup system nor there was centralized diesel generator set. Most of the houses used inverter battery backup system and few used solar as backup system

Table 4.3: Backup Sources being used in surveyed houses

S. N		Numbers of houses using backup		
	Types of house	Inverter Battery Backup	Solar Inverter backup	Hybrid Solar Inverter backup
1	Type 1	2		
2	Type 2	12	1	2
3	Type 3	2		1

4.3 Other data

Table 4.4: Other data

S.N	Type	Maximum loading (VA) at time	Average billing per month (NRs)
1	Type 1	1959 at 10 a.m	>Rs. 1050
2	Type 2	4192 at 8 a.m	>Rs. 1500
3	Type 3	4888 at 8 a.m	> Rs. 2000

4.4 Grid outage scenario

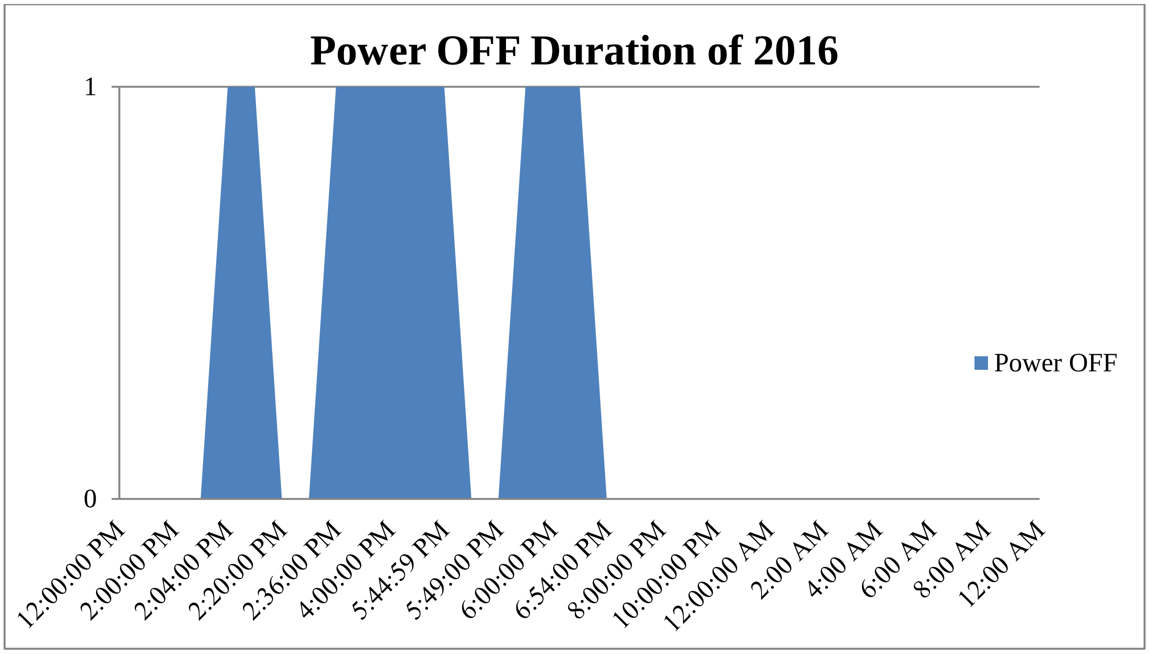


Figure 4.2: Grid Outage obtained from Time of Day Meter for 2016

As seen from the above graph, the grid outage time slots are 2:04 PM to 2:20 PM, 2:36 PM to 5:44 PM and 5:49 PM to 6:54 PM

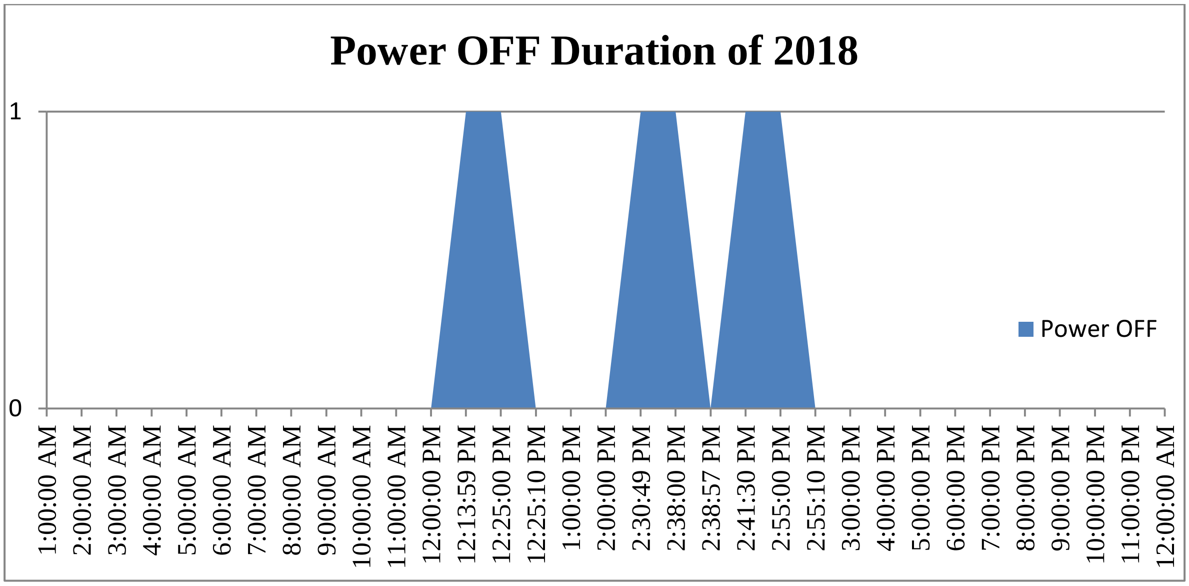


Figure 4.3: Grid Outage obtained from Time of Day Meter for 2018

As seen from the above graph, the grid outage time slots are 12:00 PM to 12:25 PM, 2:00 PM to 2:38 PM and 2:38 PM to 2:55 PM. During such power interruption, the reliable backup source could be the solar grid tied with battery backup.

4.5 Rooftop potential

As per the data sheet of mono-crystalline Canadian solar panel (Efficiency 18.0687%), 1.66 m^2 panel area is enough for 300 Wp. Since, all panels are inclined at 30 degree, rooftop potential (200 Wp is enough for 1 m^2) is calculated accordingly. Only the terrace where shading does not occur is used to calculate the solar potential.

Table 4.5: Rooftop Potential

S.N	Type	Area including all rooftop	Usable area	PV Potential(kWp)
1	Type 1	52.3 m^2	20 m^2	3.9 kWp
2	Type 2	123 m^2	24 m^2	4.8 kWp
3	Type 3	165 m^2	39 m^2	7.8 kWp
			Total	252.8 kWp

4.5 Load profile

Questionnaire used for primary data collection is attached in Annex. The summary of data collected is shown in various figures.

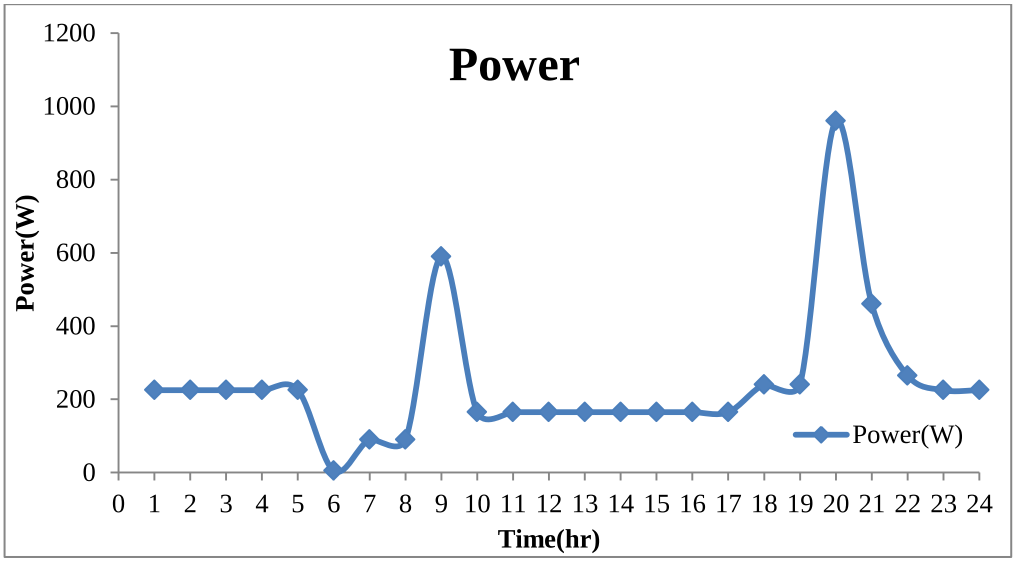


Figure 4.4: Graph of Daily Load Profile of type 1 house for weekdays

Here in this graph there is morning peak at 9 am of 590 W and evening peak at 8 pm of 960 W also the load of only 5 W is observed at 6 am in the morning

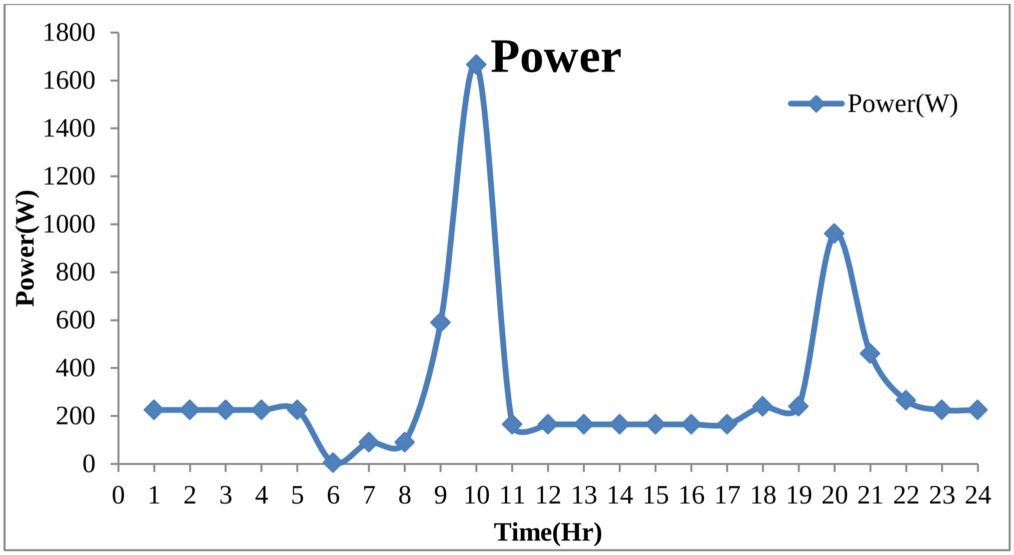


Figure 4.5: Graph of Daily Load Profile of type 1 house for weekend

Here in this graph there is morning peak at 10 am of 1665 W and evening peak at 8 pm of 960 W also the load of only 5 W is observed at 6 am in the morning.

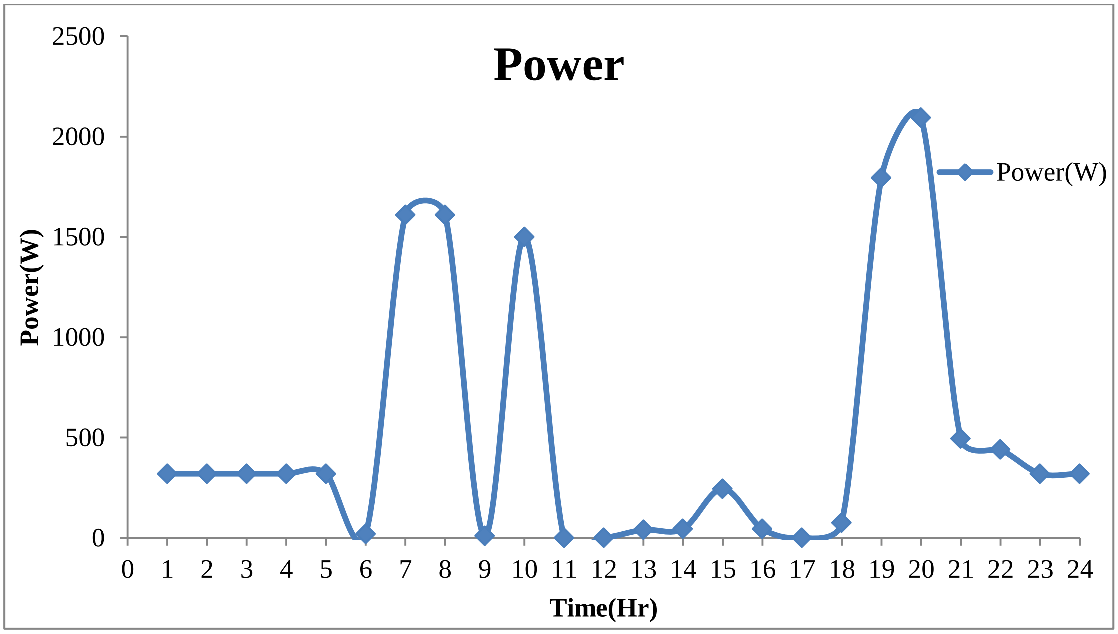


Figure 4.6: Graph of Daily Load Profile of type 2 house for weekdays

Here in this graph there is morning peak at 7 am of 1610 W, 8 am of 1610 W, 10 am of 1500 W and evening peak at 7 pm of 1795 W, 8 pm of 2095 W.

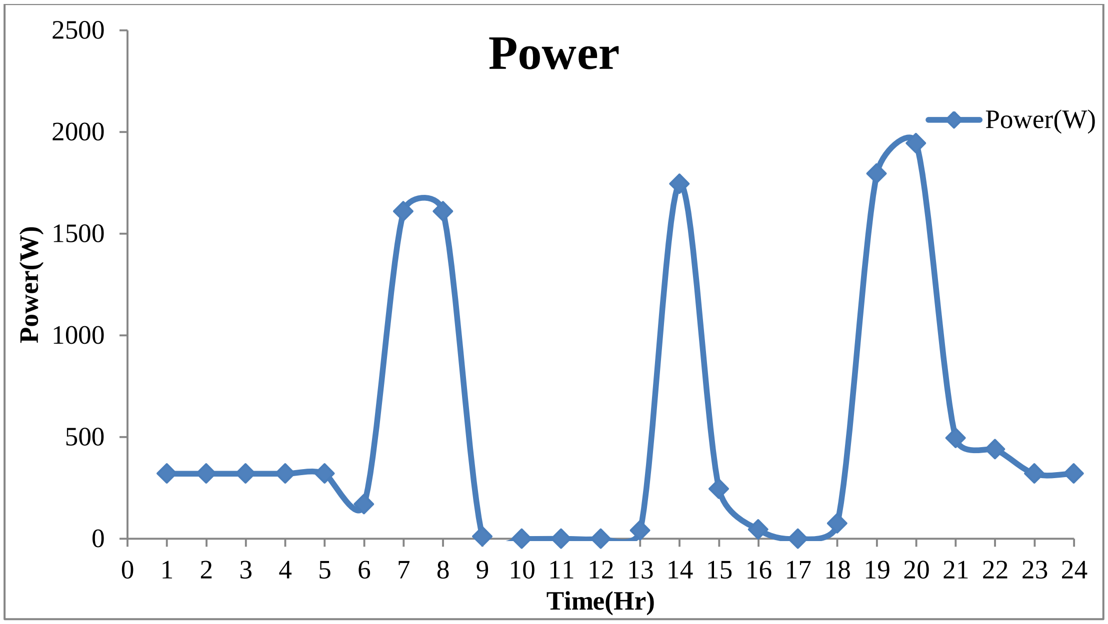


Figure 4.7: Graph of Daily Load Profile of type 2 house for weekend

Here in this graph there is morning peak at 7 am of 1610 W, 8 am of 1610 W and 2 pm of 1745 W and evening peak at 7 pm of 1795 W, 8 pm of 1945 W.

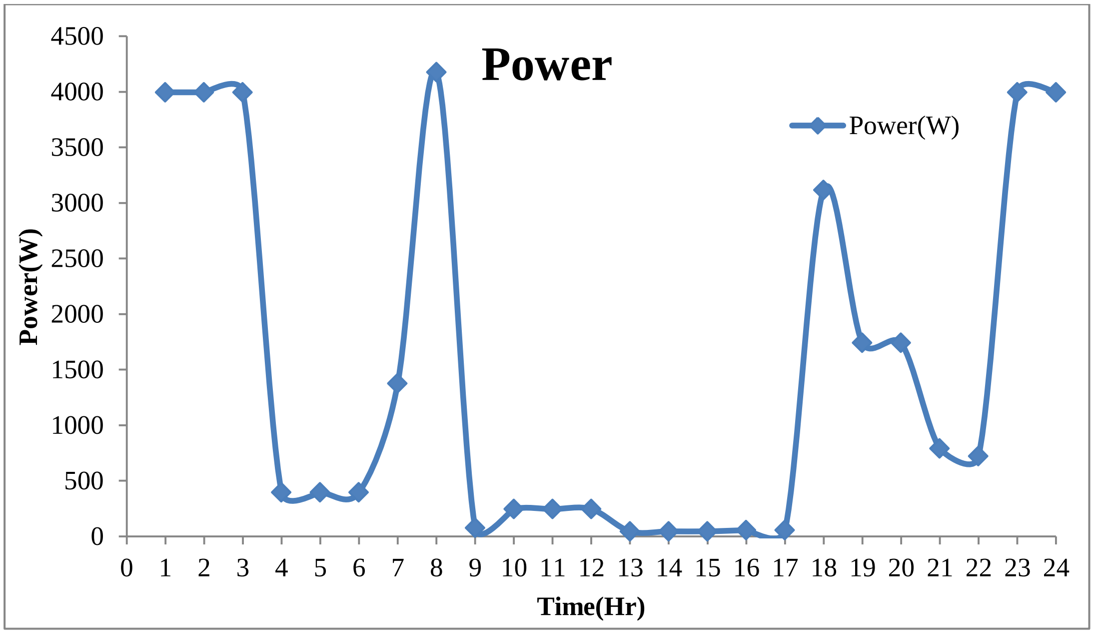


Figure 4.8: Graph of Daily Load Profile of type 3 house for weekdays

Here in this graph we can see maximum load during night cause of electrical vehicle, there is morning peak at 8 am of 4175 W and evening peak at 6 pm of 3115 W.

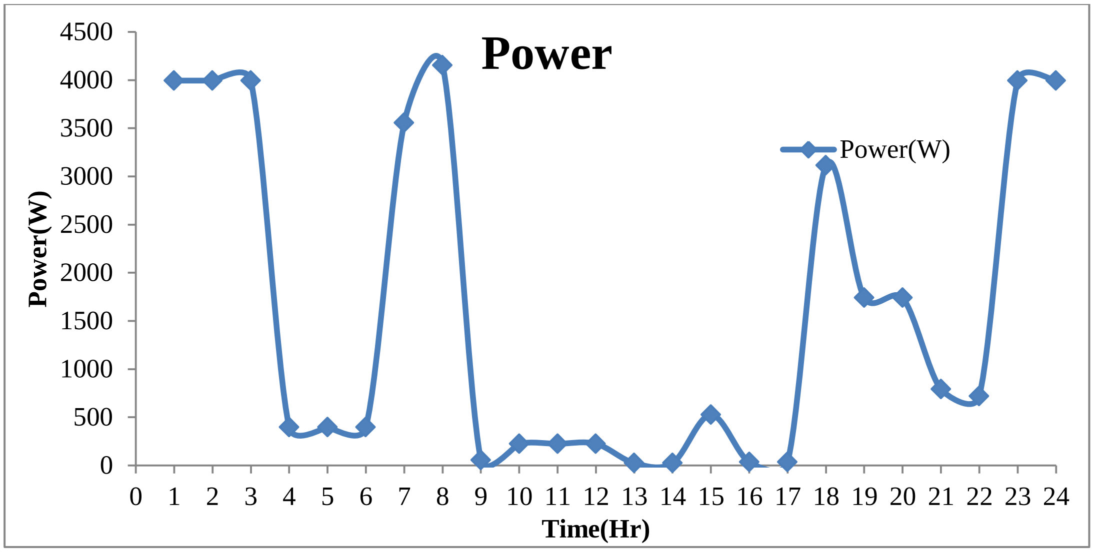


Figure 4.9: Graph of Daily Load Profile of type 3 house for weekend

Here in this graph we can see maximum load during night cause there is electrical vehicle, there is morning peak at 7 am of 3555 W , 8 am of 4155 W and evening peak at 6 pm of 3115 W.

4.6 Energy and power consumption pattern

The energy and power consumption pattern of the houses that were surveyed are presented in the bar chart shown below:

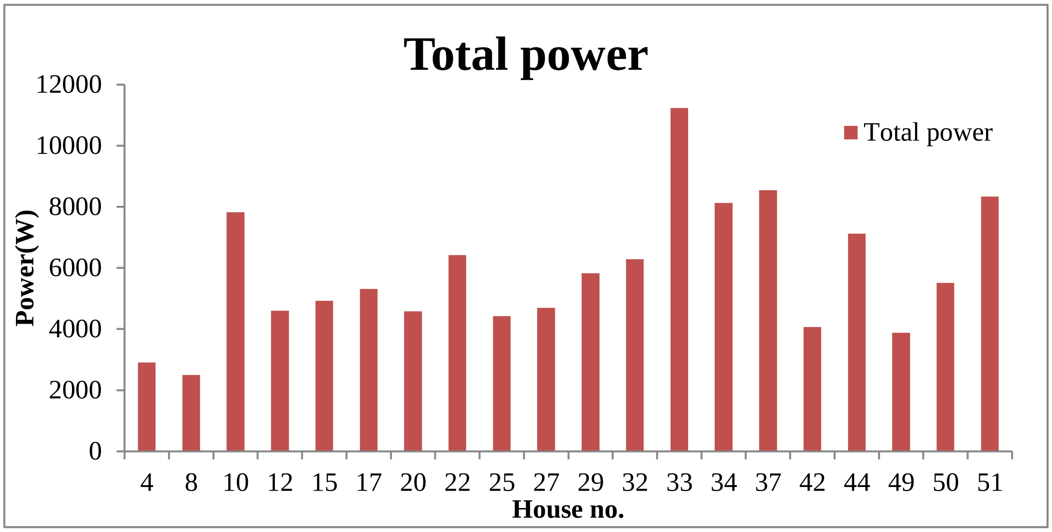


Figure 4.10: Bar chart of the Total Power Consumption of houses in weekend

Here in the graph the house no 33 has maximum power consumption and house no 8 has minimum power consumption.

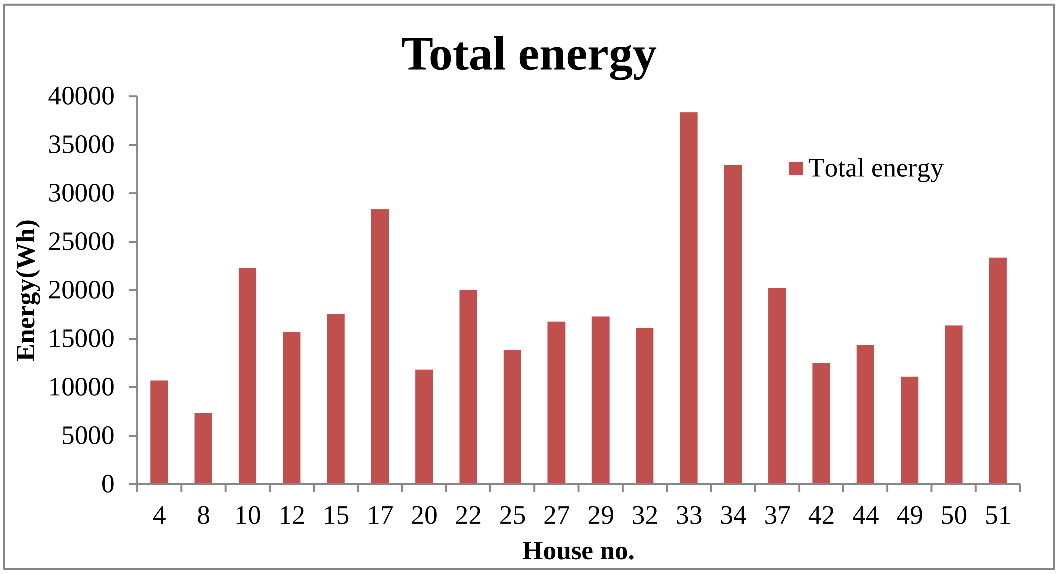


Figure 4.11: Bar chart of the Total Energy Consumption of houses in weekend

Here in the graph the house no 33 has maximum energy consumption and house no 8 has minimum energy consumption.

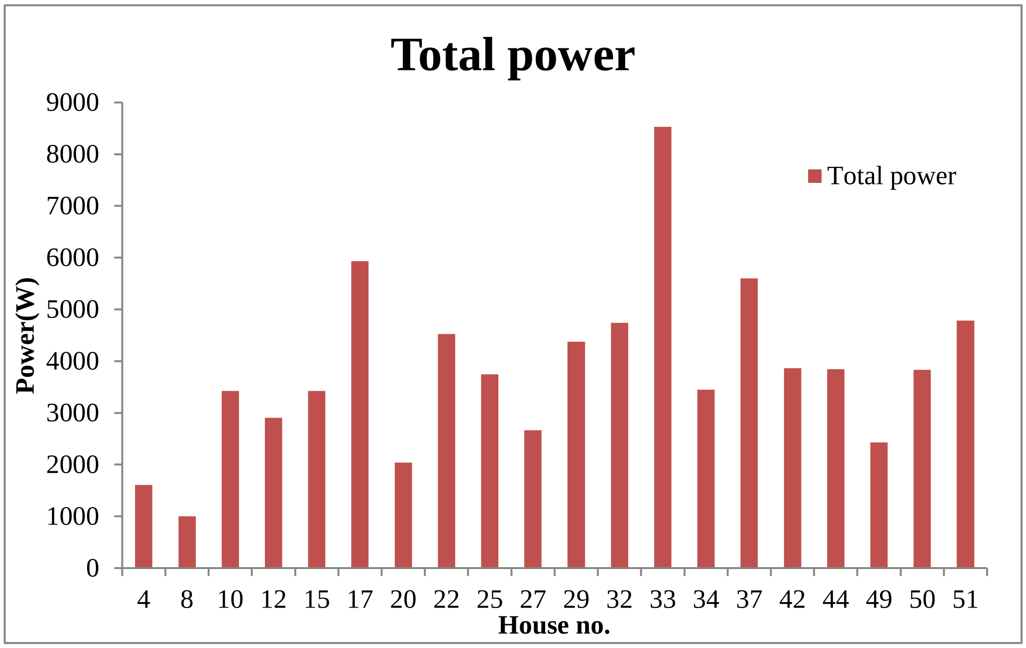


Figure 4.12: Bar chart of the Daily Power Consumption of houses in weekdays

Here in the graph the house no 33 has maximum power consumption and house no 8 has minimum power consumption.

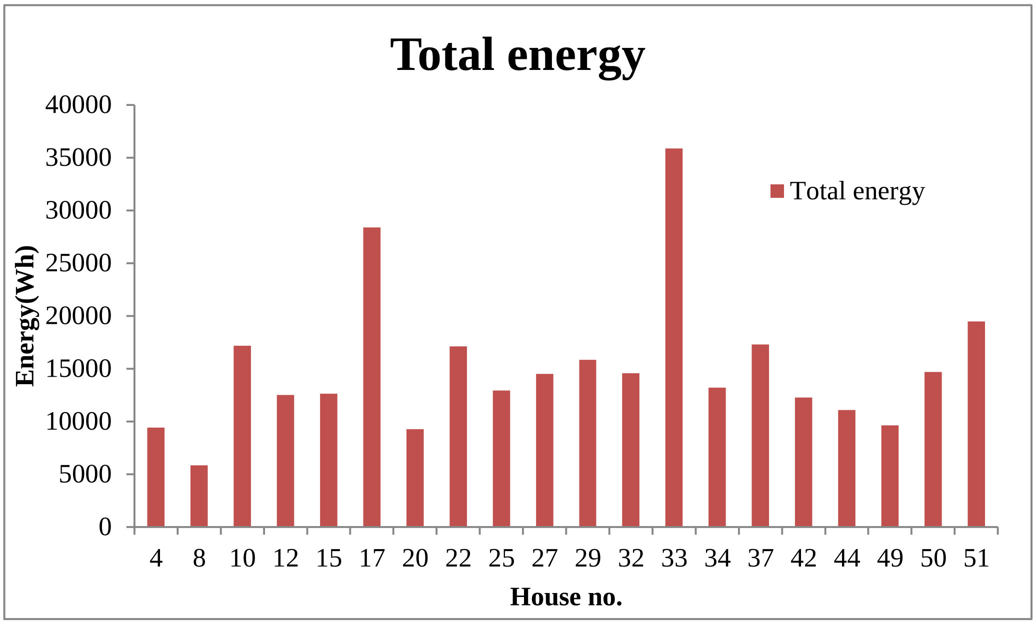


Figure 4.13: Bar chart of the Daily Energy Consumption of houses in weekdays

Here in the graph the house no 33 has maximum energy consumption and house no 8 has minimum energy consumption.

4.7 Design as standalone without grid

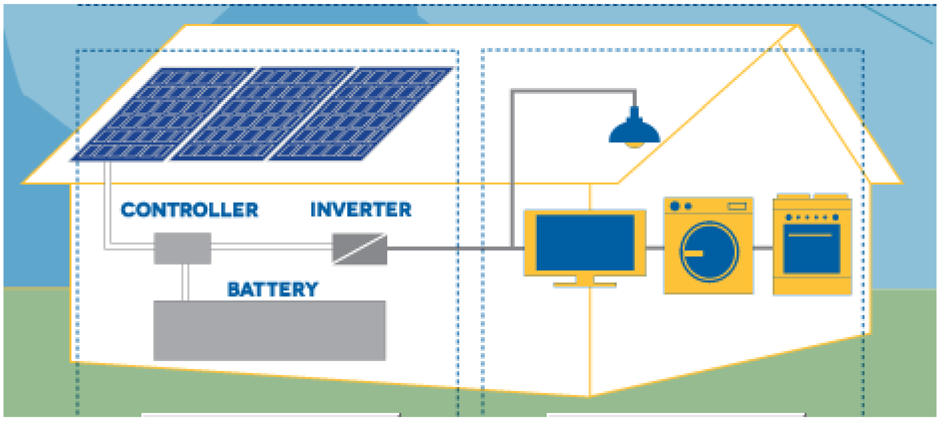


Figure 4.14: Standalone typical simulation diagram.

Design as per load requirement

a) <u>Design for type 1</u>

First of all the average daily consumption was calculated and the design was proceed:

Average dc energy consumption: 6301.34 Wh/day

<u>For battery bank sizing</u>

Selecting battery of 160 Ah, 12.8 V LFP-CB

Number of batteries in series: 2

Number of batteries in parallel: 2

Voltage/ Capacity: 26 V / 322 Ah

For array sizing

Selecting PV module of polycrystalline CS6P-270P MIX 8.73 A, 30.9 V, 270 Wp

Number of module in series: 1

Number of module in parallel: 6.32 = 6 nos

Total Watt peak of the system: 1620Wp

For inverter sizing

Maximum VA of inverter: 2 kVA Luminous Solar Inverter

Simulation for one of the above designed standalone system (type 1)

PVSYST is used for the simulation, as SAM (System Advisor Model) Software doesn’t simulate for the stand alone systems.

The simulation results obtained are:

The total nominal power of PV module: 1620 Wp

Number of modules: 6

Number of battery units: 4

Battery voltage/capacity: 26 V / 322 Ah

Total available energy: 3066.6 kWh/year

Total used energy: 2146.7 kWh/year

Total excess(unused) energy: 795 kWh/year

Specific production: 1893 kWh/kWp/year

Performance ratio: 57.09%

Solar Fraction: 97.23%

Time fraction: 3.0%

Missing Energy: 61 kWh/year

The input parameters for the stand alone system designed using PVSyst is as same as that of the system designed using MS-Excel for the comparative analysis. From the simulation it is seen that the available energy is 3066.6 kWh/year and the used energy is 2146.7 kWh/year. The unused energy is 795 kWh/year. The unused energy is the excess energy generated by the system that is wasted when it is not required by the load and the battery. The specific production is the generation of total energy i.e. 1893 kWh for 1 year from 1 kWp panel.

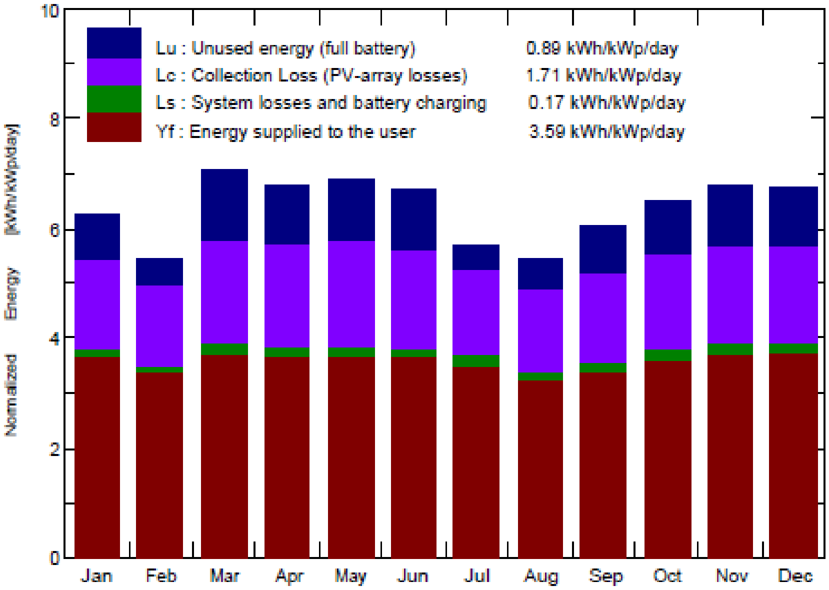


Figure 4.15: Energy production for type 1 standalone system

From the figure it is seen that the unused energy is 0.89 kWh/kWp/day and the energy supplied to user is 3.59 kWh/kWp/day. The other losses are PV-array losses which is 1.71 kWh/kWp/day and Battery charging losses is 0.17 kWh/kWp/day.

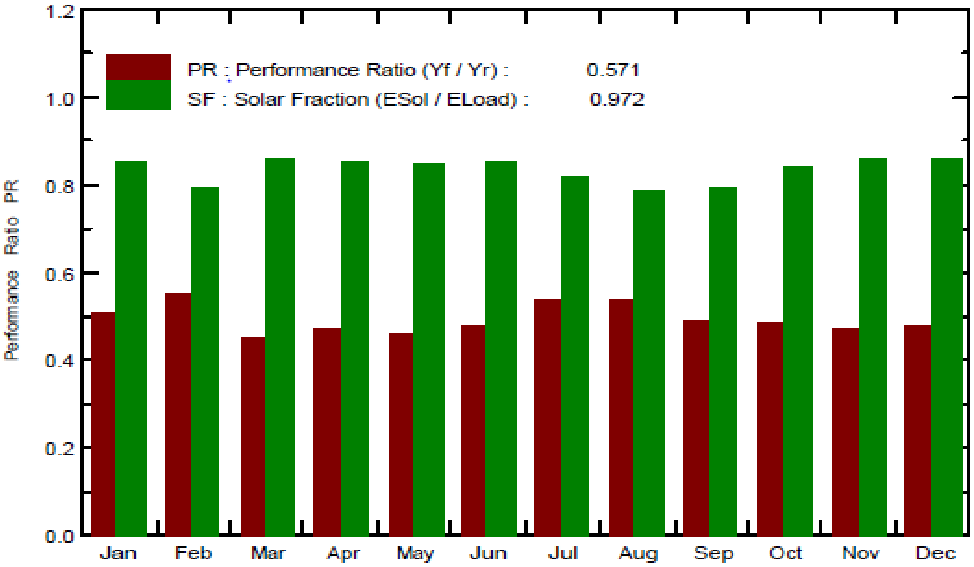
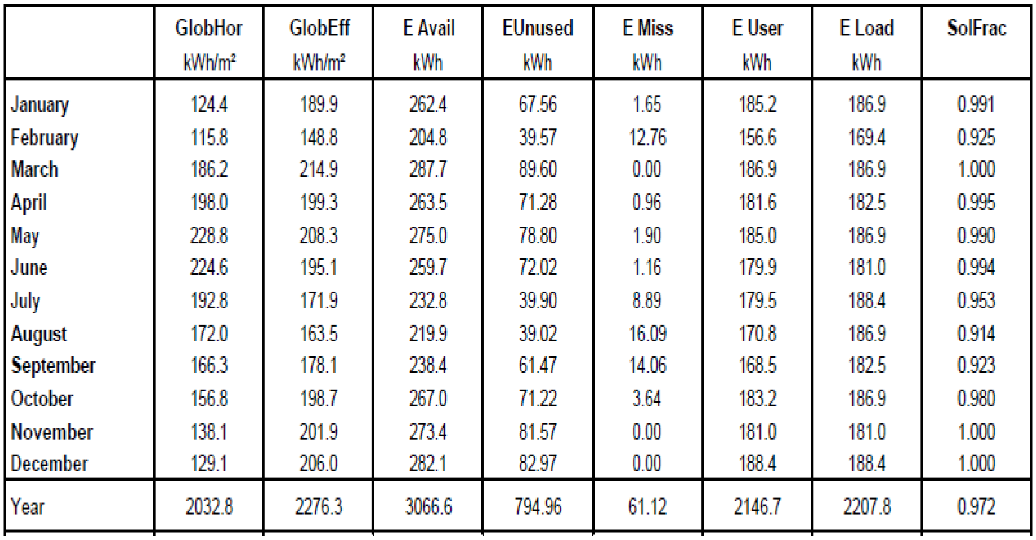


Figure 4.16: Performance ratio for type 1 standalone system

From the total energy generated from the solar, all the energy could not be utilized, neither by the load nor by the grid. This is unused energy in the system that could be supplied to the grid but is treated as the loss. Therefore, we observe the performance ratio to be 57.1% .Solar fraction is the calculation of the solar energy available used by the load. Since during night time the load is fulfilled by the battery, so the value of solar fraction is near about 0.972.

Table 4.6: Main balance and results for type 1 standalone system



	GlobHor kWh/m²	GlobEff kWh/m²	E Avail kWh	EUnused kWh	E Miss kWh	E User kWh	E Load kWh	SolFrac
January	124.4	189.9	262.4	67.56	1.65	185.2	186.9	0.991
February	115.8	148.8	204.8	39.57	12.76	156.6	169.4	0.925
March	186.2	214.9	287.7	89.60	0.00	186.9	186.9	1.000
April	198.0	199.3	263.5	71.28	0.96	181.6	182.5	0.995
May	228.8	208.3	275.0	78.80	1.90	185.0	186.9	0.990
June	224.6	195.1	259.7	72.02	1.16	179.9	181.0	0.994
July	192.8	171.9	232.8	39.90	8.89	179.5	188.4	0.953
August	172.0	163.5	219.9	39.02	16.09	170.8	186.9	0.914
September	166.3	178.1	238.4	61.47	14.06	168.5	182.5	0.923
October	156.8	198.7	267.0	71.22	3.64	183.2	186.9	0.980
November	138.1	201.9	273.4	81.57	0.00	181.0	181.0	1.000
December	129.1	206.0	282.1	82.97	0.00	188.4	188.4	1.000
Year	2032.8	2276.3	3066.6	794.96	61.12	2146.7	2207.8	0.972

The main results tabulated shows the total available energy, total unused energy, total missing energy, total energy supplied to user, total energy need of user and the average solar fraction. The yearly energy available is 3066.6 kWh, yearly energy supplied to user by solar is 2146.7 kWh, yearly energy required by load is 2207.8 kWh.

Emissing= Total energy need - Total energy supplied= Eload-Euser = 61.12 kWh

Eunused= Total available energy-Energy output of array=Eavail-Earray= 794.96 kWh

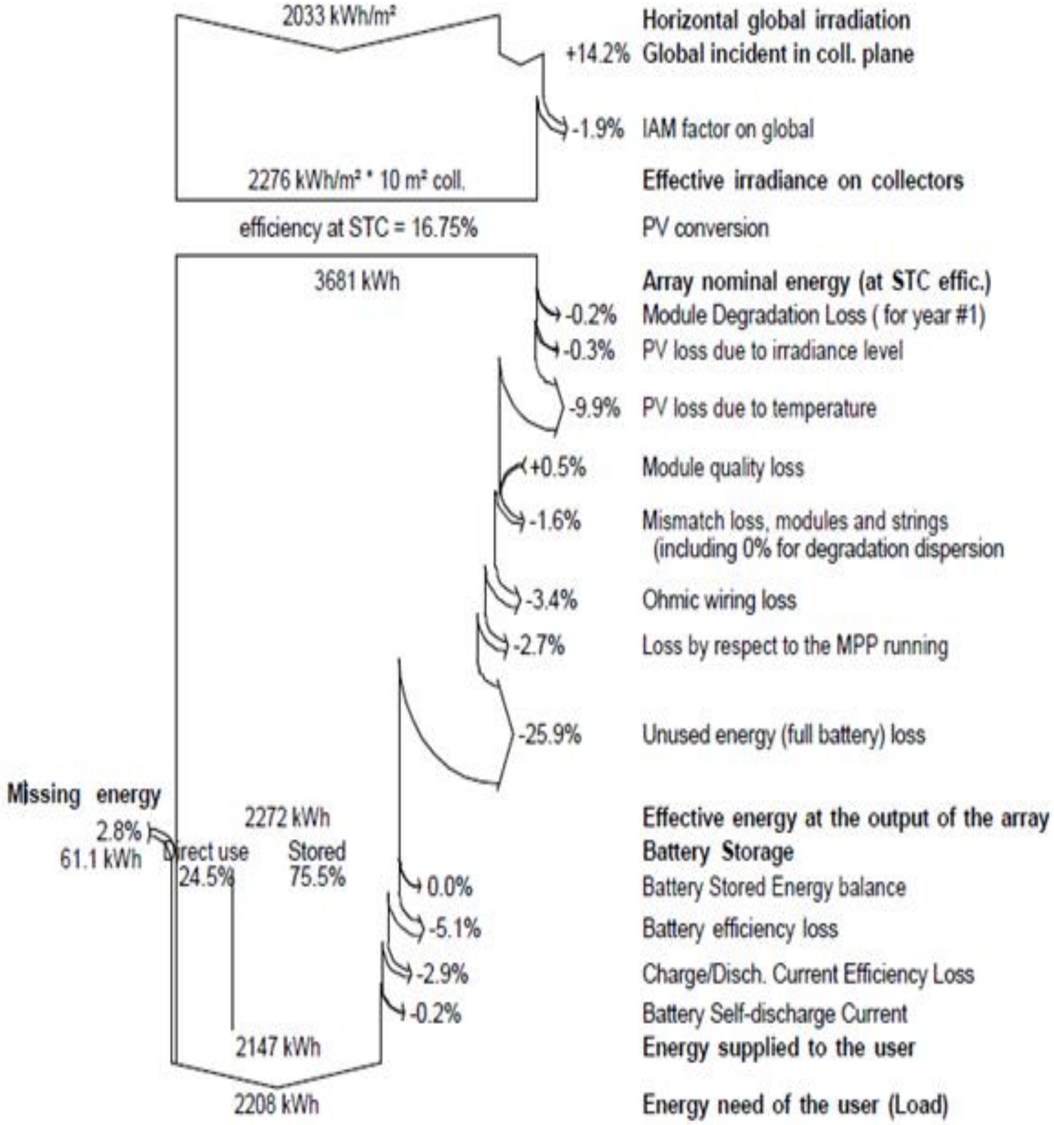


Figure 4.17: Loss Diagram for type 1 standalone system

Here in the loss diagram, there is 25.9% unused energy. This is energy that could be supplied to the grid but being a standalone system this is wasted when battery is fully charged. Another major loss is from the missing energy that is 2.8% that is difference of the energy need of user and energy supplied to user. Other minor loss are shown in the diagram.

b) Design for type 2:

First of all the average daily consumption was calculated and the design is summarized as below:

Average dc energy consumption: 12465 Wh/day

For battery bank sizing

Selecting battery of 103 Ah, 12.8 V LFP-CB

Number of batteries in series: 4

Number of batteries in parallel: 3

Voltage/ Capacity: 51 V / 302 Ah

For array sizing

Selecting PV module of polycrystalline CS6P-270P MIX with 8.75 A, 30.9 V,270 Wp

Number of module in series: 2

Number of module in parallel: 6.32 = 6 nos

Total Watt peak of the system: 3240 Wp

For inverter sizing

Maximum VA of inverter: 3 kVA Luminous Solar Inverter

Simulation for one of the above designed standalone system (type 2)

PVSYST is used for the simulation, as SAM(System Advisor Model) Software doesn't simulate for the stand alone systems.

The simulation results obtained are:

The total nominal power of PV module:3240 Wp

Number of modules: 12

Number of battery units: 12

Battery voltage/capacity: 51 V/302 Ah

Total available energy: 6300 kWh/year

Total used energy: 4356 kWh/year

Total excess(unused) energy: 1744 kWh/year

Specific production: 1945 kWh/kWp/year

Performance ratio: 58.163%

Solar Fraction: 97.06%

Time fraction: 2.3 %

Missing Energy: 131 kWh/year

The input parameters for the stand alone system designed using PVSyst is as same as that of the system designed using MS-Excel for the comparative analysis. From the simulation it is seen that the available energy is 6300 kWh/year and the used energy is 4361 kWh/year. The unused energy is 1739 kWh/year.

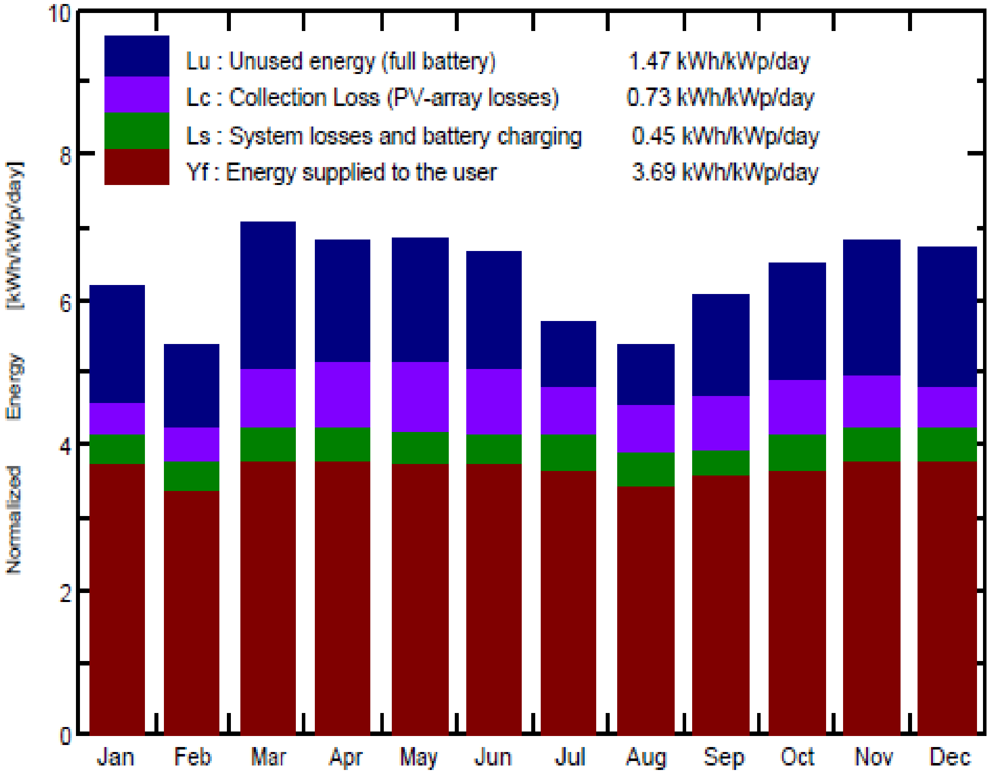


Figure 4.18: Energy production for type 2 standalone system

From the figure it is seen that the unused energy is 1.47 kWh/kWp/day and the energy supplied to user is 3.69 kWh/kWp/day. The other losses are PV-array losses which is 0.73 kWh/kWp/day and Battery charging losses is 0.45 kWh/kWp/day.

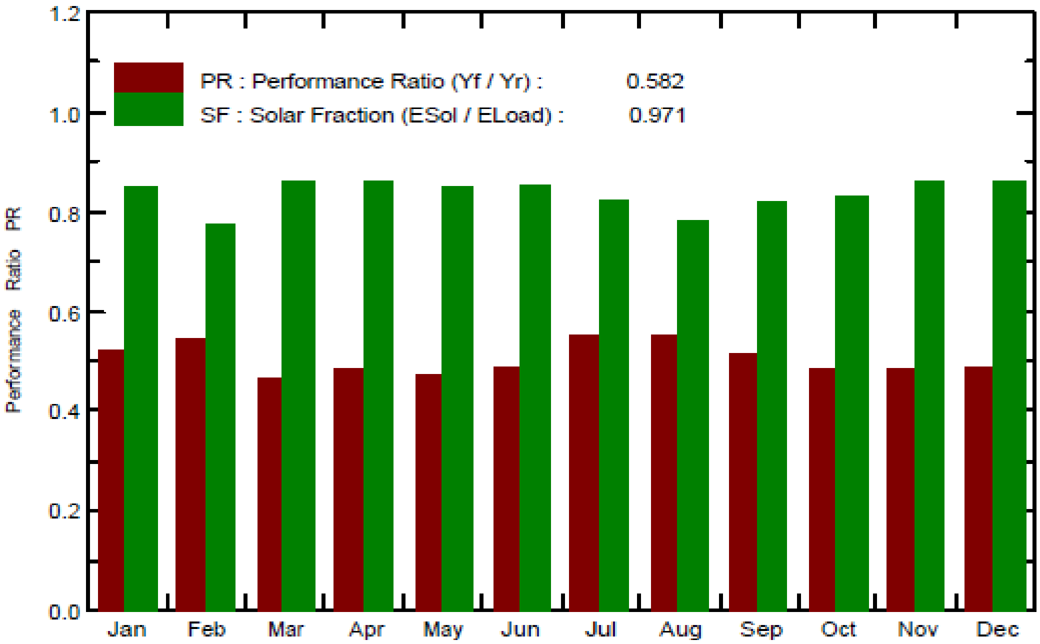
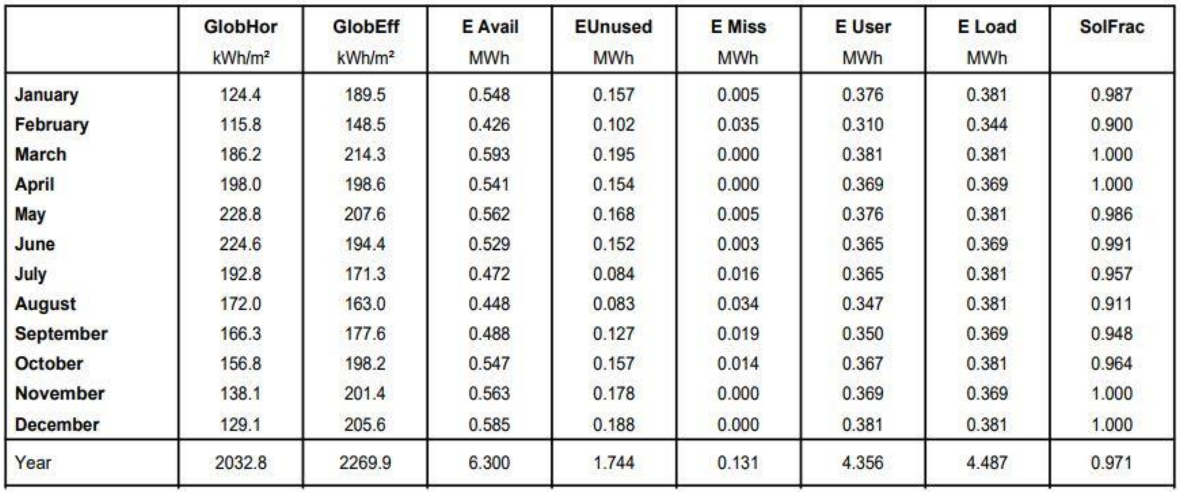


Figure 4.19: Performance ratio for type 2 standalone system

We observe the performance ratio to be 58.2% and the value of solar fraction is near about 0.971.

Table 4.7: Main balance and results for type 2 standalone system



	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	124.4	189.5	0.548	0.157	0.005	0.376	0.381	0.987
February	115.8	148.5	0.426	0.102	0.035	0.310	0.344	0.900
March	186.2	214.3	0.593	0.195	0.000	0.381	0.381	1.000
April	198.0	198.6	0.541	0.154	0.000	0.369	0.369	1.000
May	228.8	207.6	0.562	0.168	0.005	0.376	0.381	0.986
June	224.6	194.4	0.529	0.152	0.003	0.365	0.369	0.991
July	192.8	171.3	0.472	0.084	0.016	0.365	0.381	0.957
August	172.0	163.0	0.448	0.083	0.034	0.347	0.381	0.911
September	166.3	177.6	0.488	0.127	0.019	0.350	0.369	0.948
October	156.8	198.2	0.547	0.157	0.014	0.367	0.381	0.964
November	138.1	201.4	0.563	0.178	0.000	0.369	0.369	1.000
December	129.1	205.6	0.585	0.188	0.000	0.381	0.381	1.000
Year	2032.8	2269.9	6.300	1.744	0.131	4.356	4.487	0.971

The yearly energy available is 6300 kWh, yearly energy supplied to user by solar is 4356 kWh and yearly energy required by load is 4487 kWh.

Emissing= Total energy need - Total energy supplied= Eload-Euser = 131 kWh

Eunused= Total available energy-Energy output of array=Eavail-Earray= 1744 kWh

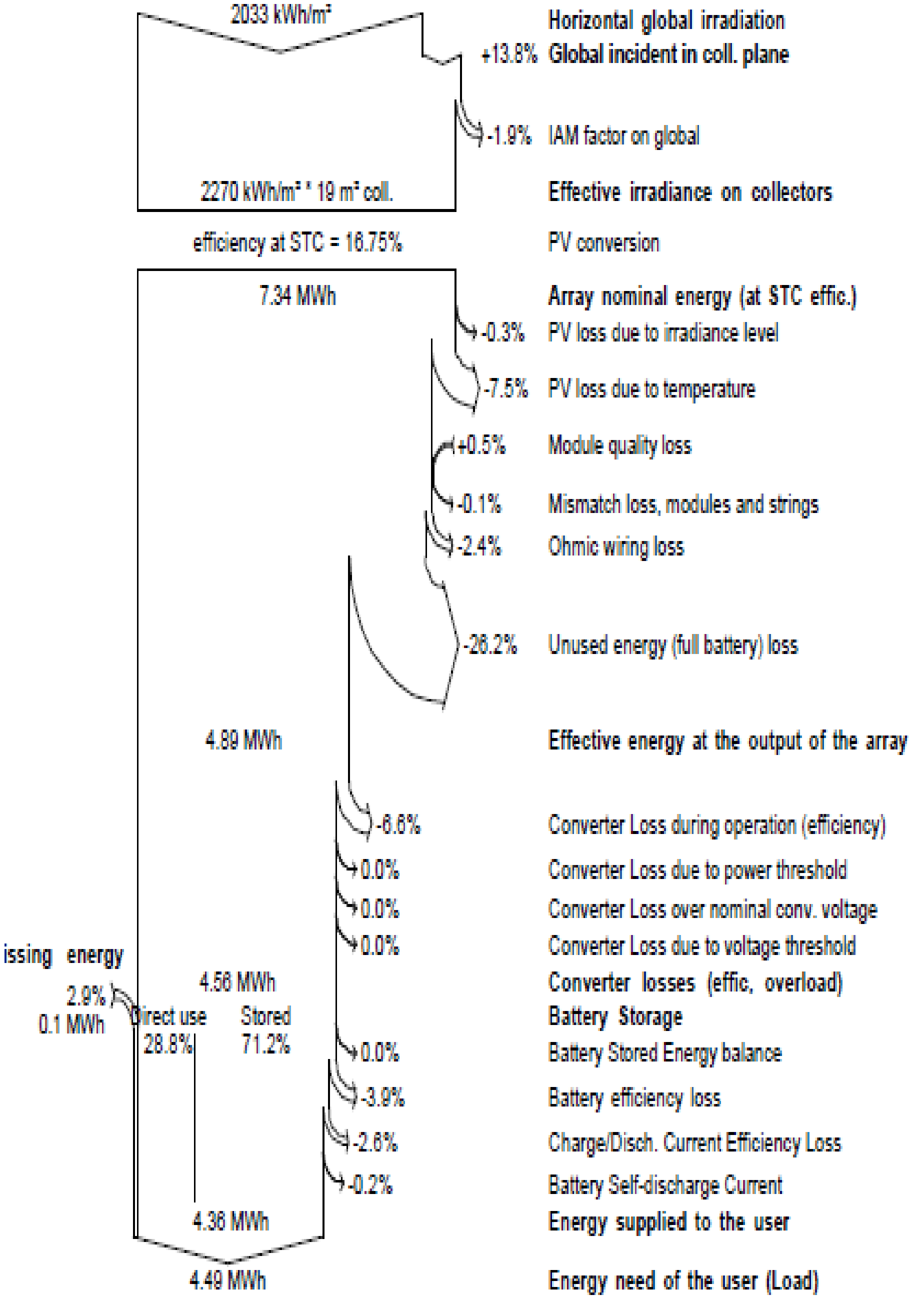


Figure 4.20: Loss Diagram for type 2 standalone system

Here in the loss diagram, there is 26.2% unused energy. This is energy that could be supplied to the grid but being a standalone system this is wasted when battery is fully charged. Another major loss is from the missing energy that is 2.9% that is difference of the energy need of user and energy supplied to user. Other minor loss are shown in the diagram.

c) <u>Design for type 3:</u>

First of all the average daily consumption was calculated and the design is summarised as below:

Average dc energy consumption: 22360 Wh/day

<u>For battery bank sizing</u>

Selecting battery of 101 Ah, 12.8 V LFP-CB

Number of batteries in series: 6

Number of batteries in parallel: 4

Voltage/ Capacity: 77 V / 413 Ah

<u>For array sizing</u>

Selecting PV module of polycrystalline CS6P-270P MIX with 8.75 A, 30.9 V,270 Wp

Number of module in series: 3

Number of module in parallel: 8 nos

Total Watt peak of the system: 6480 Wp

<u>For inverter sizing</u>

Maximum VA of inverter: 5 kVA Luminous Solar Inverter

<u>Simulation for one of the above designed standalone system (type 3)</u>

PVSYST is used for the simulation, as SAM(System Advisor Model) Software doesn’t simulate for the stand alone systems.

The simulation results obtained are:

The total nominal power of PV module:6480 Wp

Number of modules: 24

Number of battery units: 24

Battery voltage/capacity: 77 V/413 Ah

Total available energy: 9592 kWh/year

Total used energy: 7778 kWh/year

Total excess(unused) energy: 1429 kWh/year

Specific production: 1480 kWh/kWp/year

Performance ratio: 51.87%

Solar Fraction: 95.23%

Time fraction: 4.4 %

Missing Energy: 389 kWh/year

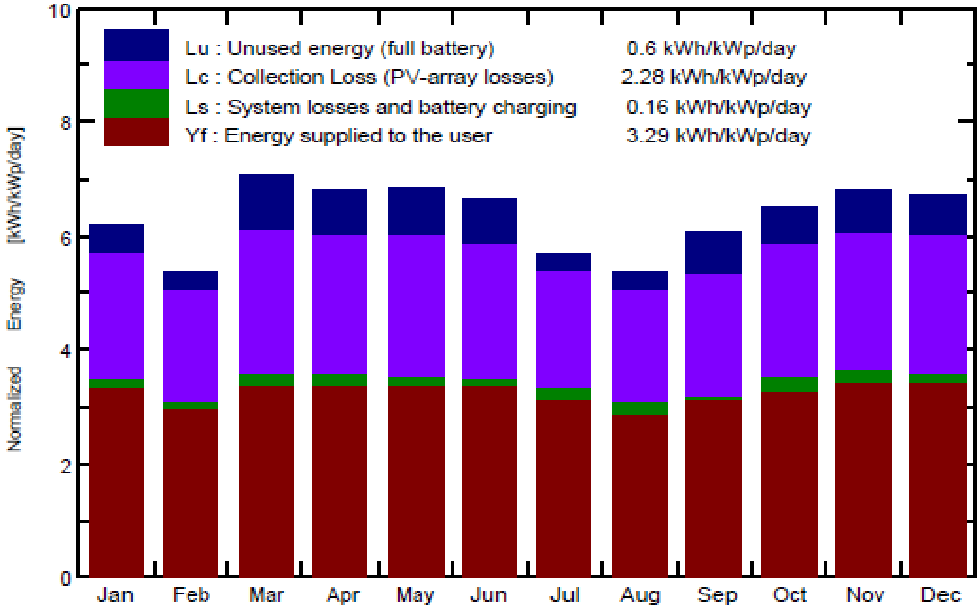


Figure 4.21: Energy production for type 3 standalone system

From the figure it is seen that the unused energy is 0.6 kWh/kWp/day and the energy supplied to user is 3.29 kWh/kWp/day. The other losses are PV-array losses which is 2.28 kWh/kWp/day and Battery charging losses is 0.16 kWh/kWp/day.

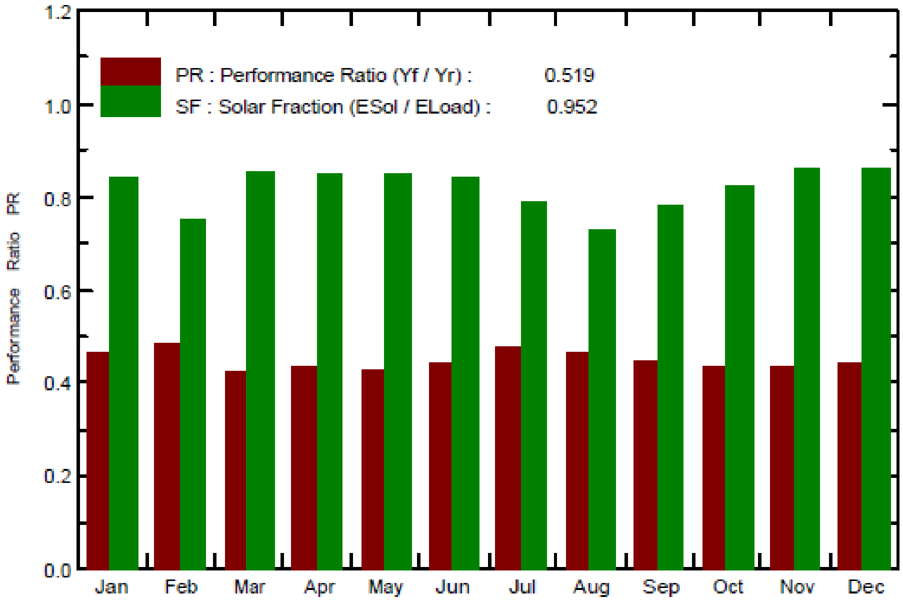
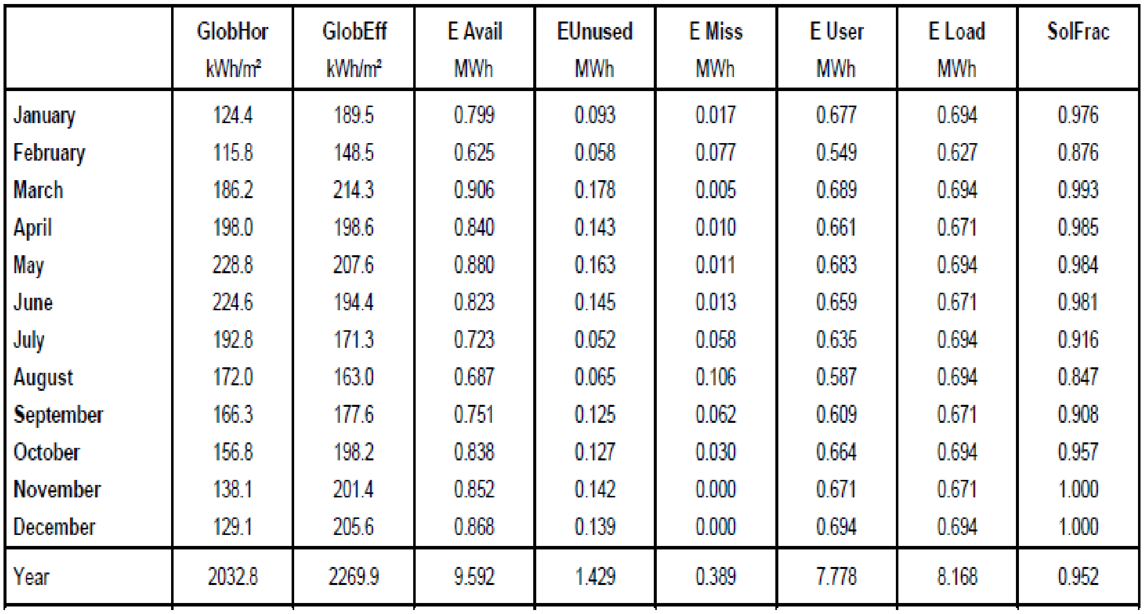


Figure 4.22: Performance ratio for type 3 standalone system

We observe the performance ratio to be 51.9% and the value of solar fraction is near about 0.952.

Table 4.8: Main balance and results for type 3 standalone system



	GlobHor kWh/m²	GlobEff kWh/m²	E Avail MWh	EUnused MWh	E Miss MWh	E User MWh	E Load MWh	SolFrac
January	124.4	189.5	0.799	0.093	0.017	0.677	0.694	0.976
February	115.8	148.5	0.625	0.058	0.077	0.549	0.627	0.876
March	186.2	214.3	0.906	0.178	0.005	0.689	0.694	0.993
April	198.0	198.6	0.840	0.143	0.010	0.661	0.671	0.985
May	228.8	207.6	0.880	0.163	0.011	0.683	0.694	0.984
June	224.6	194.4	0.823	0.145	0.013	0.659	0.671	0.981
July	192.8	171.3	0.723	0.052	0.058	0.635	0.694	0.916
August	172.0	163.0	0.687	0.065	0.106	0.587	0.694	0.847
September	166.3	177.6	0.751	0.125	0.062	0.609	0.671	0.908
October	156.8	198.2	0.838	0.127	0.030	0.664	0.694	0.957
November	138.1	201.4	0.852	0.142	0.000	0.671	0.671	1.000
December	129.1	205.6	0.868	0.139	0.000	0.694	0.694	1.000
Year	2032.8	2269.9	9.592	1.429	0.389	7.778	8.168	0.952

The yearly energy available is 9592 kWh, yearly energy supplied to user by solar is 7778 kWh and yearly energy required by load is 8168 kWh.

Emissing= Total energy need - Total energy supplied= Eload-Euser = 389 kWh

Eunused= Total available energy-Energy output of array=Eavail-Earray= 1429 kWh

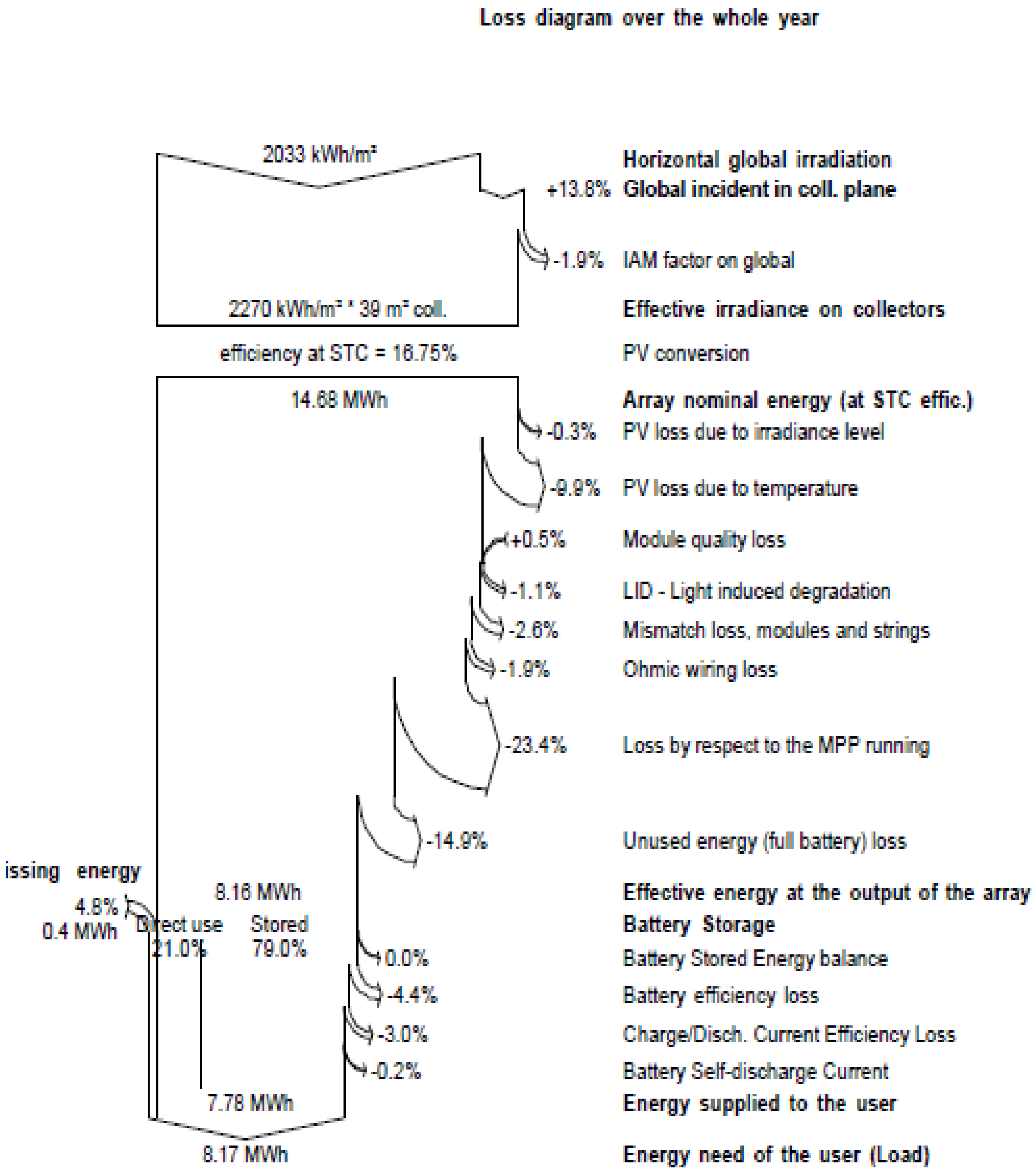


Figure 4.23: Loss Diagram for type 3 standalone system

Here in the loss diagram, there is 23.4% unused energy. This is energy that could be supplied to the grid but being a standalone system this is wasted when battery is fully charged. Another major loss is from the missing energy that is 4.8% that is difference of the energy need of user and energy supplied to user. Other minor loss are shown in the diagram.

4.8 Design of PV grid tied system

Simulation using SAM (System Advisory Model)

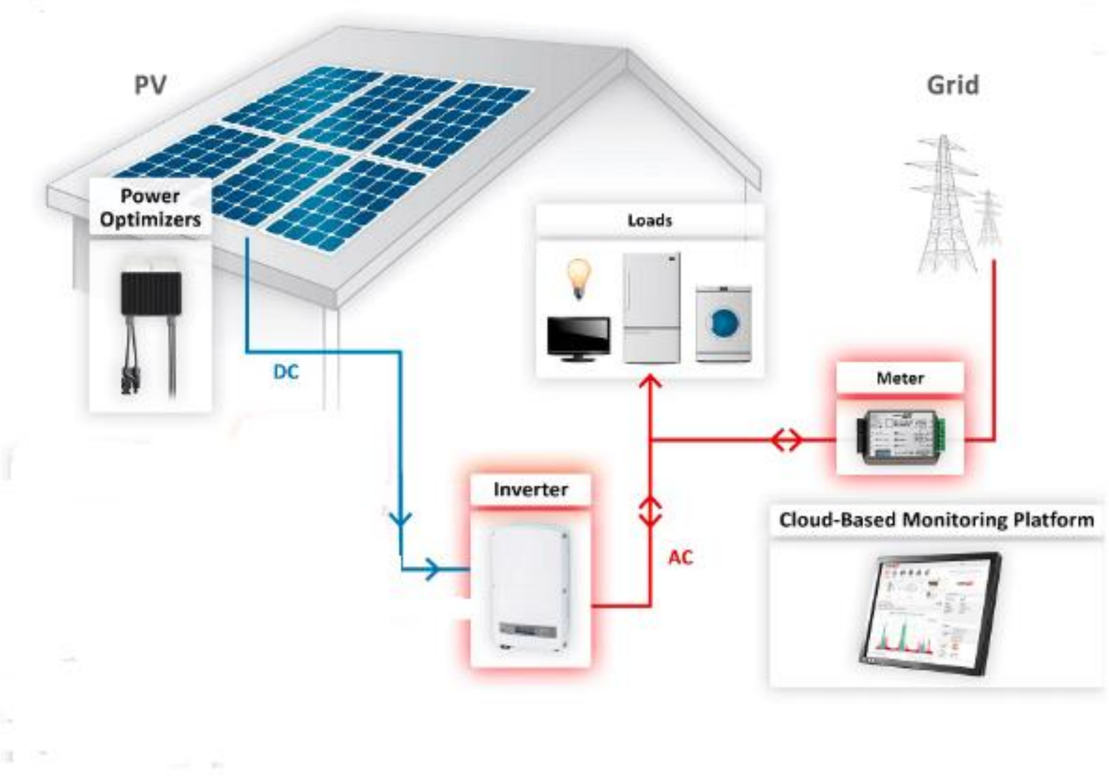


Figure 4.24: Simulation Diagram for grid tied PV system

a) <u>Design for type 1 system</u>

Rooftop Potential = 3.9 kWp

Module Selection:

Canadian Solar Inc. CS1K-300MS

Cell material highly efficient Mono-c-Si

Module area 1.6 m^2

Module capacity 300.3 DC Watts

Nominal efficiency: 18.316%

No of Modules required: 3900/300 = 13

For Optimum Layout 13 modules are selected.

Total module area: 20.8 m^2

Rooftop area required on 30 degree inclination installation= 18 m^2

Inverter Sizing:

In order to facilitate the efficient design of PV systems, the nominal AC power output from the inverter shall not be less than 75% of the array peak power and it shall not be outside the inverter's maximum allowable array size specifications.

Inverter should be > 0.75 x 13 x 300 = 2925 W

Considering single efficient string inverter, Solar Edge Technology brand 2962 AC Wattage with 98% efficiency is selected.

SolarEdge Technologies Ltd: SE3000H-US

Unit capacity 2.962 AC kW

Input voltage 360 - 480 VDC

Quantity :1

Total capacity 2.96 AC kW

DC to AC Capacity Ratio 1.22

PV Array Sizing:

For the best performance of the system, the output voltage of the solar array should be matched to the operating voltages of the inverter. To minimize the risk of damage to the inverter, the maximum voltage of the inverter shall never be reached.

Minimum Voltage window of the inverter= 360+0.05* 360= 378 V

Maximum Voltage window of the inverter= 480-0.05*480= 456 V

Minimum No of Module in series = 378 / (32.5*0.97) = 11.99

Maximum No of Module in series = 456 / (32.5*0.97) = 31.525

As per the potential, we select 13 number of PV modules in series.

Total power= 13*300=3900 Wp

Thus, sizing in SAM is done as below,

Total AC capacity: 2.962 kWac

Total inverter DC capacity: 2.987 kWac

Total number of modules: 13

Total number of strings: 1

Total module area: 20.8 m^2

The simulation results are shown below:

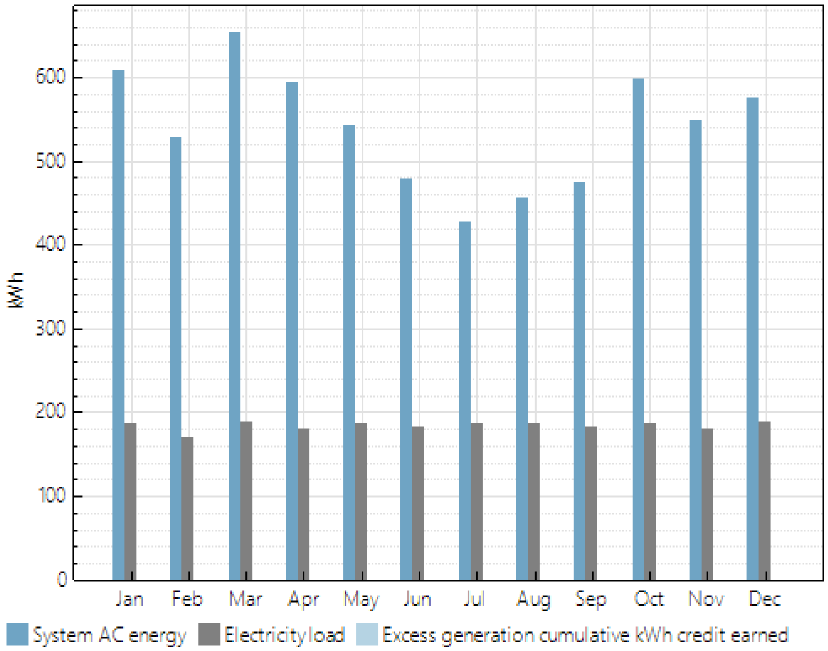


Figure 4.25: Monthly energy flow to the load and excess energy for type 1

The monthly energy production from the PV is maximum in March that is 653.29 kWh and minimum is in July that is 426.33 kWh.The maximum electric load is 188.38 kWh for March. The excess energy generation cumulative is not shown because it is the net metering system where billing is done is monthly basis.

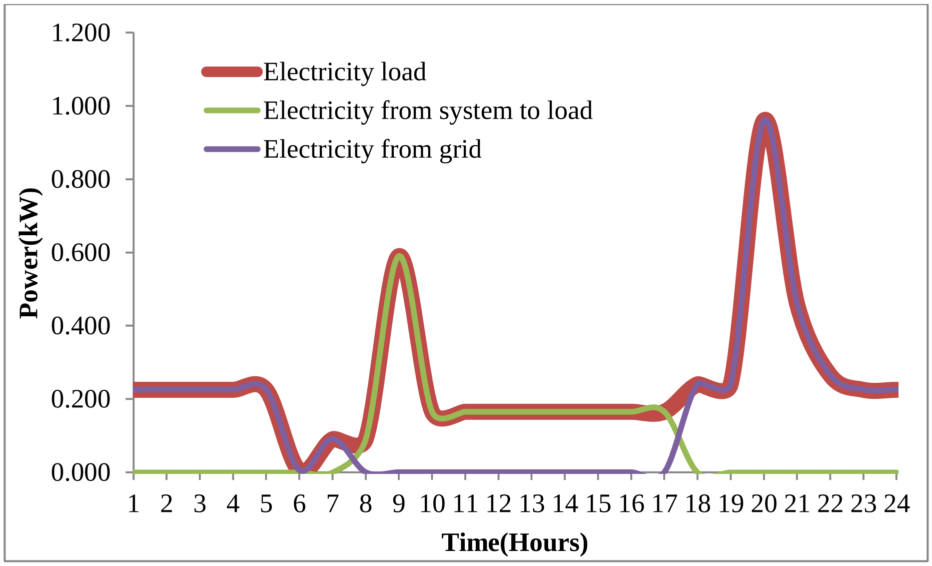


Figure 4.26: Electricity from PV to load, grid to load for weekdays for type 1

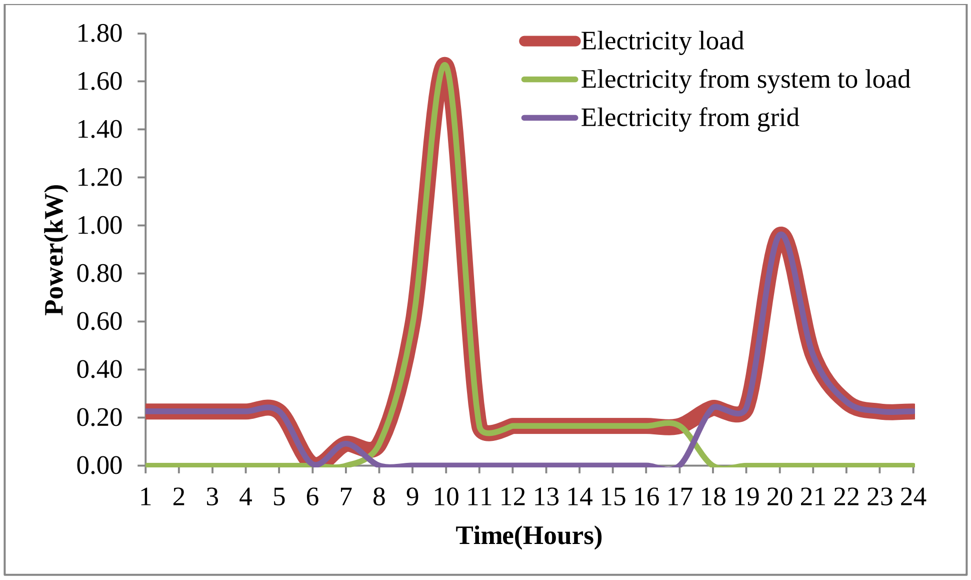


Figure 4.27: Electricity from PV to load, grid to load for weekend for type 1

Here in this figure we can observe the load vary for Weekdays and Weekend. Here the maximum load supplied from grid is 0.96 kW at 8 pm for weekdays and weekends. The maximum load supplied from PV is 0.59 kW at 9 am for weekdays and 1.66 kW at 10 am for weekend. Since there is no solar during the night, the night load is completely dependent upon the grid whereas during day time when there is surplus solar the load is fed by PV.

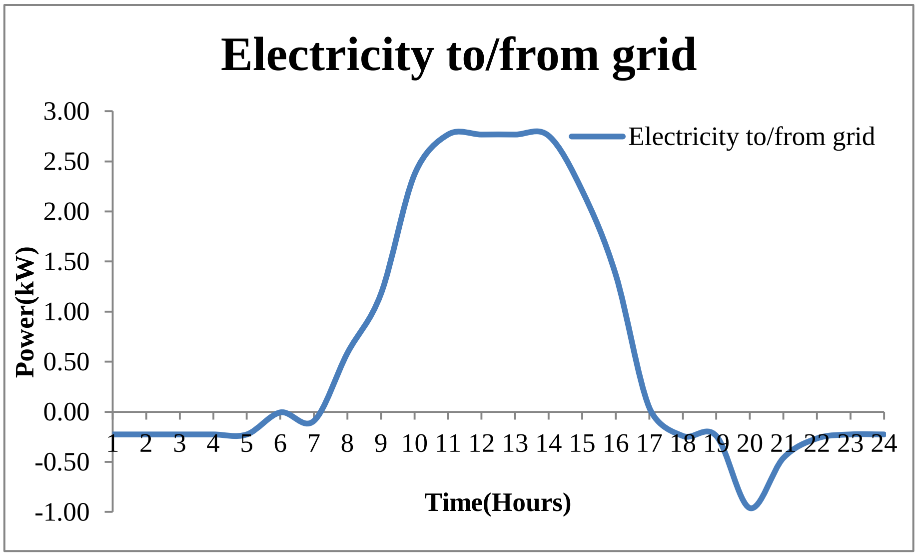


Figure 4.28: Electricity to/from grid after PV system installed for weekdays for type 1

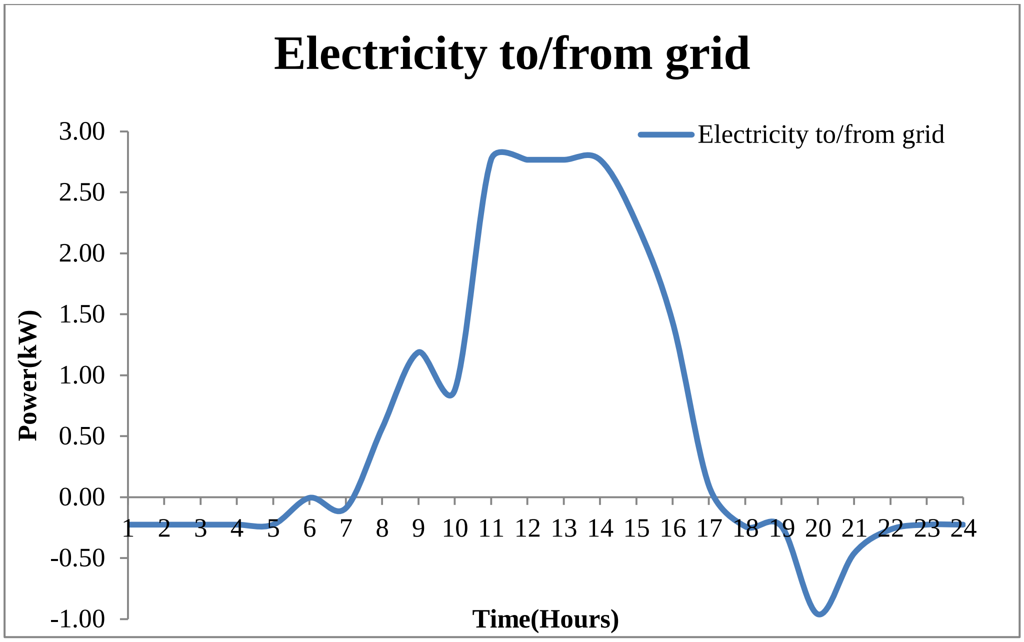


Figure 4.29: Electricity to/ from grid after installation of system in weekend for type 1

Here in the figure we can observe the electricity to and from the grid. The maximum power supplied to the grid is 2.75 kW at 12 pm whereas the power supplied from grid is 0.96 kW at 8 pm for the weekdays and weekends.

b) Design for type 2 system

Rooftop Potential = 4.8 kWp

Module Selection:

Canadian Solar Inc. CS1K-300MS

Cell material highly efficient Mono-c-Si

Module area 1.6 m²

Module capacity 300.3 DC Watts

Nominal efficiency:18.316%

No of Modules required: 4800/300 = 16

For Optimum Layout 16 modules are selected.

Total module area: 25.6 m^2

Rooftop area required on 30 degree inclination installation= 22 m^2

Inverter Sizing:

In order to facilitate the efficient design of PV systems, the nominal AC power output from the inverter shall not be less than 75% of the array peak power and it shall not be outside the inverter's maximum allowable array size specifications.

Inverter should be > 0.75 x 16 x 300 = 3600 W

Considering single efficient string inverter, Solar Edge Technology brand 3970 AC Wattage with 97.269% efficiency is selected.

SolarEdge Technologies Ltd: SE4000
Unit capacity: 3.970 AC kW
Input voltage: 370 - 500 VDC
Quantity :1
Total capacity : 3.97 AC kW
DC to AC Capacity Ratio: 1.21

PV Array Sizing:

For the best performance of the system, the output voltage of the solar array should be matched to the operating voltages of the inverter. To minimize the risk of damage to the inverter, the maximum voltage of the inverter shall never be reached.

Minimum Voltage window of the inverter= 370+0.05* 370= 388.5 V
Maximum Voltage window of the inverter= 500-0.05*500= 475 V
Minimum No of Module in series = 388 / (29.8*0.97) = 13.44
Maximum No of Module in series = 476 / (29.8*0.97) = 16.46
As per the potential, we select 16 number of PV modules in series.
Total power= 16*300=4800 Wp
Thus, sizing in SAM is done as below,
Total AC capacity: 3.970 kW
Total number of modules: 16
Total number of strings: 1
The simulation results are shown below:

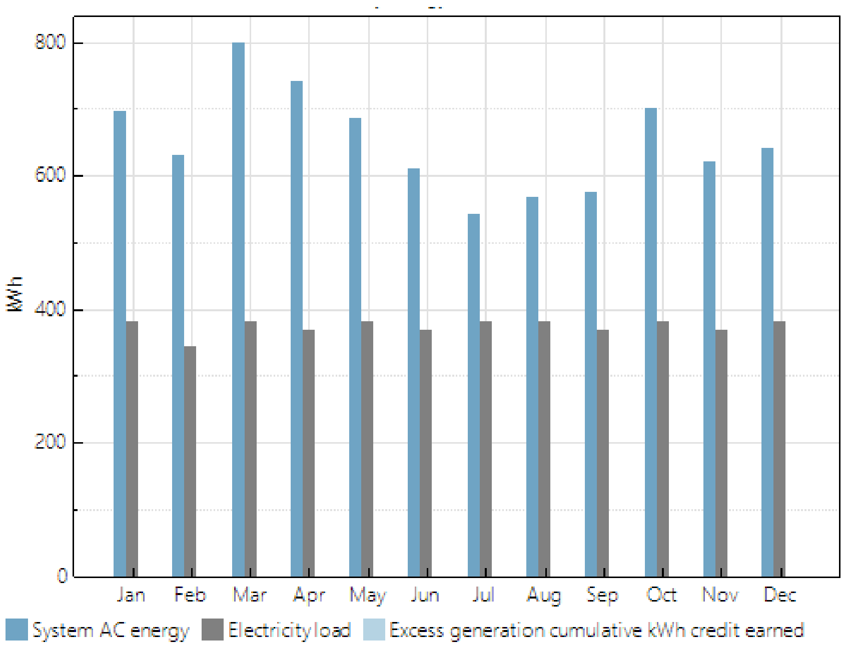


Figure 4.30: Monthly energy flow to the load and excess energy for type 2

The monthly energy production from the PV is maximum in March that is 798.85 kWh and minimum is in July that is 542.19 kWh. The maximum electric load is 381.01 kWh for March. The excess energy generation cumulative is not shown because it is the net metering system where billing is done is monthly basis.

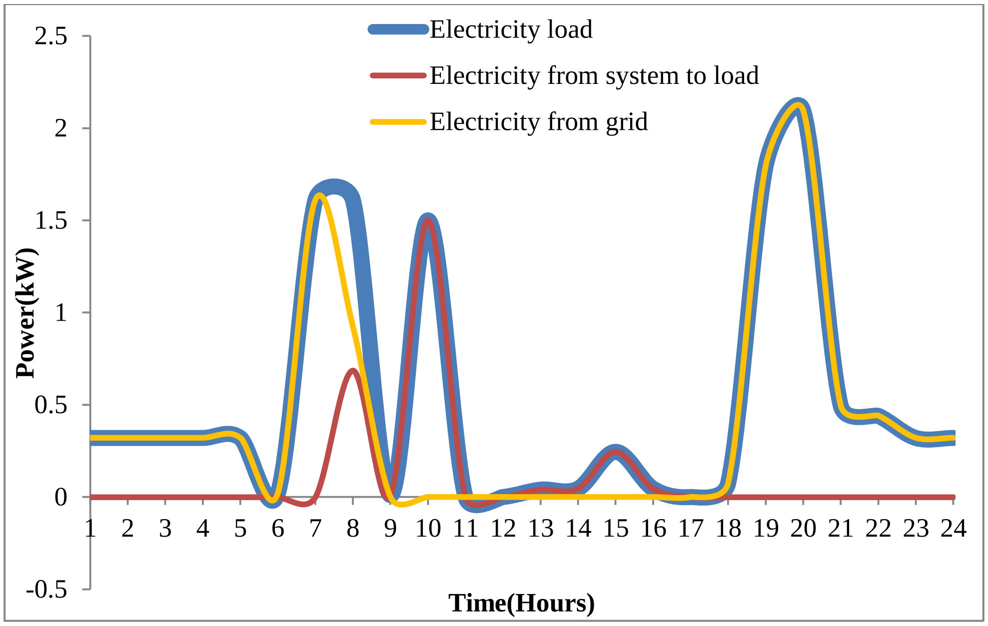


Figure 4.31: Electricity from PV to load, grid to load for weekdays for type 2

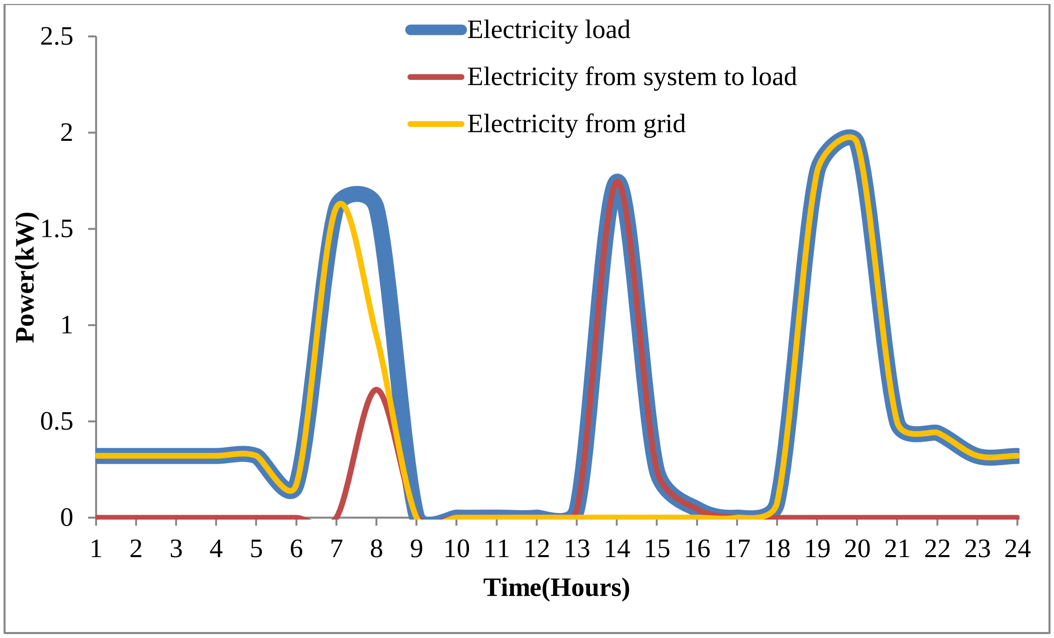


Figure 4.32: Electricity from PV to load, grid to load for weekend for type 2

Here the maximum load supplied from grid is 2.09 kW and 1.94 kW at 8 pm for weekdays and weekends respectively. The maximum load supplied from PV is 1.5 kW at 10 am for weekdays and 1.74 kW at 2 pm for weekends. Since there is no solar during the night, the night load is completely dependent upon the grid whereas during day time when there is surplus solar the load is fed by PV.

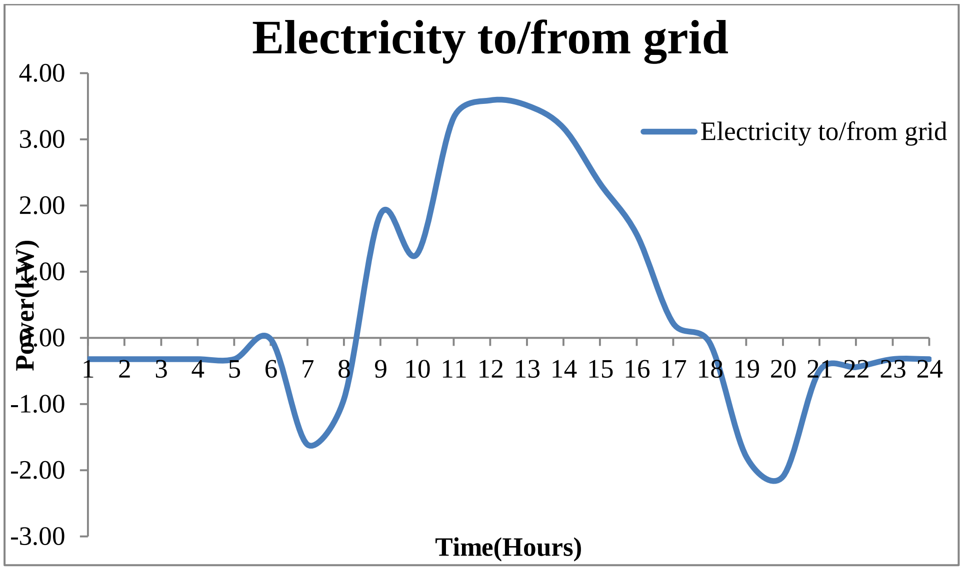


Figure 4.33: Electricity to/from grid after PV system installed for weekdays for type 2

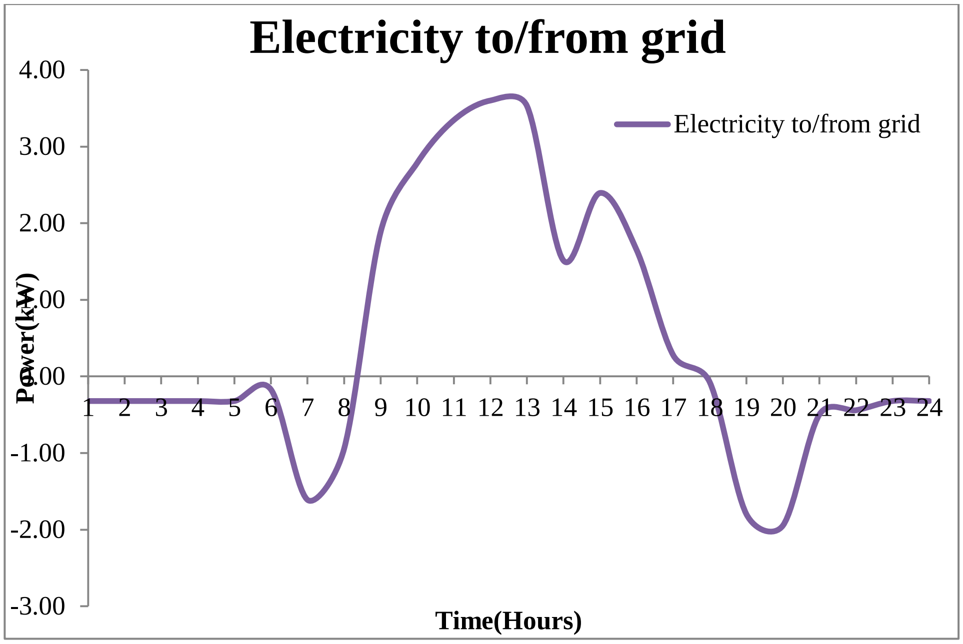


Figure 4.34: Electricity to/from grid after PV system installed for weekend for type 2

Here in the figure we can observe the electricity to and from the grid. The maximum power supplied to the grid is 3.59 kW at 12 pm for weekdays and weekend whereas the power supplied from grid is 2.09 kW and 1.94 kW at 8 pm for the weekdays and weekends respectively.

c) <u>Design for Type 3 system</u>

Rooftop Potential = 7.8 kWp

Module Selection:

Canadian Solar Inc. CS1K-300MS

Cell material highly efficient Mono-c-Si

Module area 1.6 m²

Module capacity 300.3 DC Watts

Nominal efficiency:18.316%

No of Modules required: 7800/300 = 26

For Optimum Layout 26 modules are selected.

Total module area: 42 m^2

Inverter Sizing:

In order to facilitate the efficient design of PV systems, the nominal AC power output from the inverter shall not be less than 75% of the array peak power and it shall not be outside the inverter's maximum allowable array size specifications.

Inverter should be > 0.75 x 26 x 300 = 5855 W

Considering single efficient string inverter, Solar Edge Technology brand 7020 AC Wattage with 97.9% efficiency is selected.

SolarEdge Technologies Ltd: SE7000
Unit capacity: 7.020 AC kW
Input voltage: 100 - 480 VDC
Quantity :1
Total capacity : 7.020 AC kW
DC to AC Capacity Ratio: 1.11

PV Array Sizing:

For the best performance of the system, the output voltage of the solar array should be matched to the operating voltages of the inverter. To minimize the risk of damage to the inverter, the maximum voltage of the inverter shall never be reached.

Minimum Voltage window of the inverter= 100+0.05* 100= 105 V
Maximum Voltage window of the inverter= 480-0.05*480= 456 V
Minimum No of Module in series = 100 / (29.8*0.97) = 4
Maximum No of Module in series = 456 / (29.8*0.97) = 15.77

As per the potential, we select two strings of 13 number of PV modules each in series.

Total power= 2*13*300=7800 Wp

Thus, sizing in SAM is done as below,

Total AC capacity: 7.02 kWac
Total inverter DC capacity: 7.196 kWac
Total number of modules: 26
Total number of strings: 2
Total module area: 42 m^2

The simulation results are shown below:

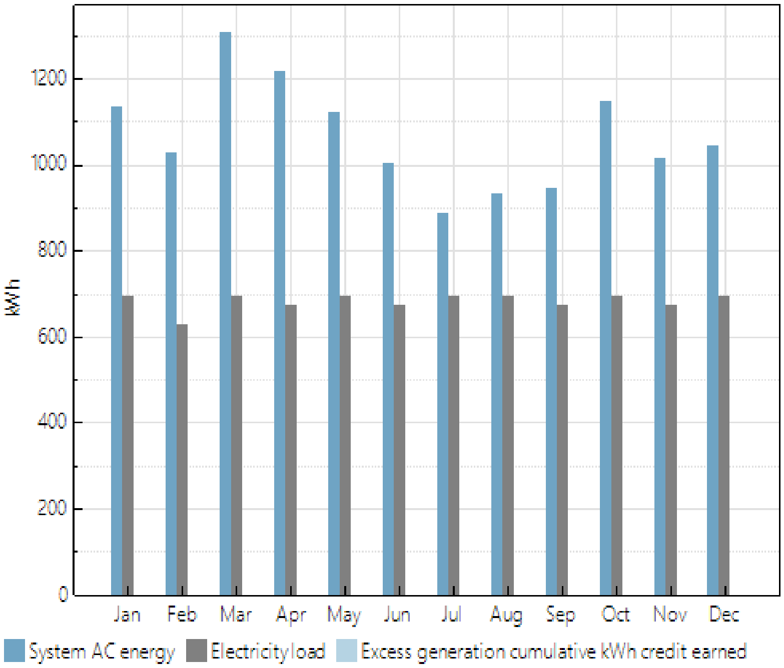


Figure 4.35: Monthly energy flow to the load and excess energy for type 3

The monthly energy production from the PV is maximum in March that is 1306.11 kWh and minimum is in July that is 888.74 kWh. The maximum electric load is 693.68 kWh for March. The excess energy generation cumulative is not shown because it is the net metering system where billing is done is monthly basis.

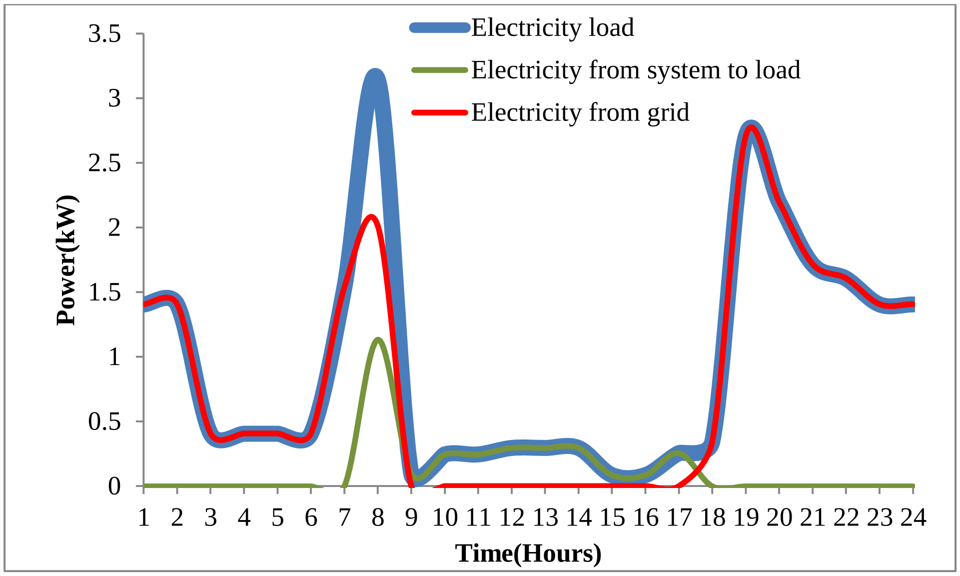


Figure 4.36: Electricity from PV to load, grid to load for weekdays for type 3

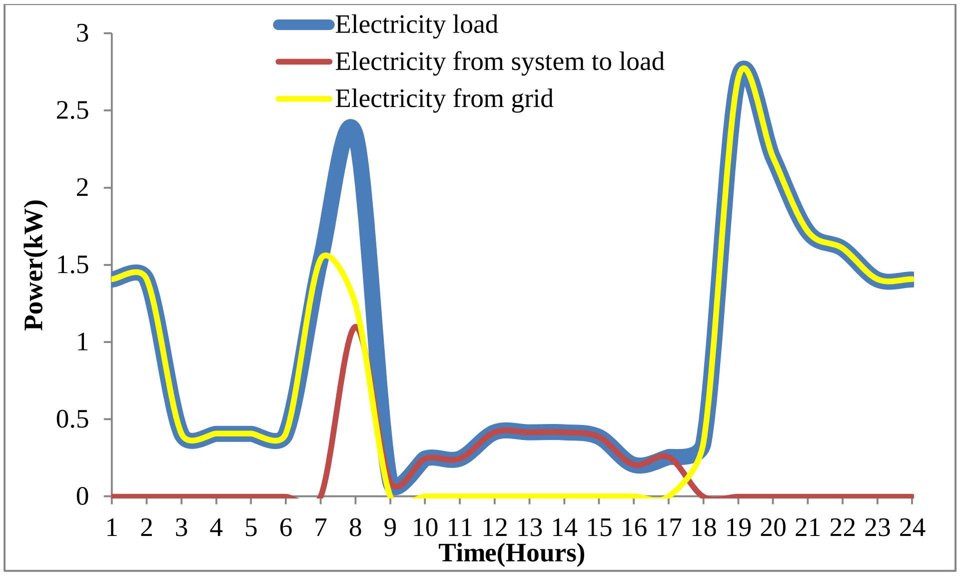


Figure 4.37: Electricity from PV to load, grid to load for weekend for type 3

Here the maximum load supplied from grid is 2.19 kW at 8 pm for weekdays and weekends. The maximum load supplied from PV is 1.13 kW and 1.09 kW at 8 am for weekdays and weekends respectively. There is the night time load of 1.41 kW for charging electric vehicle. Since there is no solar during the night, the night load is completely dependent upon the grid whereas during day time when there is surplus solar the load is fed by PV.

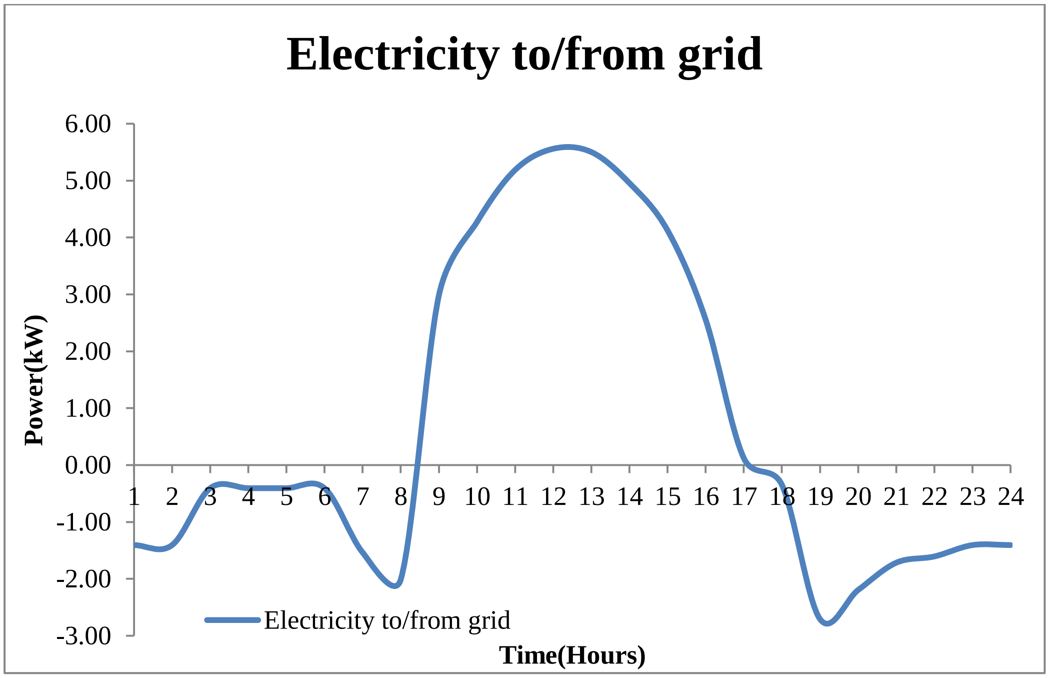


Figure 4.38: Electricity to/from grid after PV system installed for weekdays for type 3

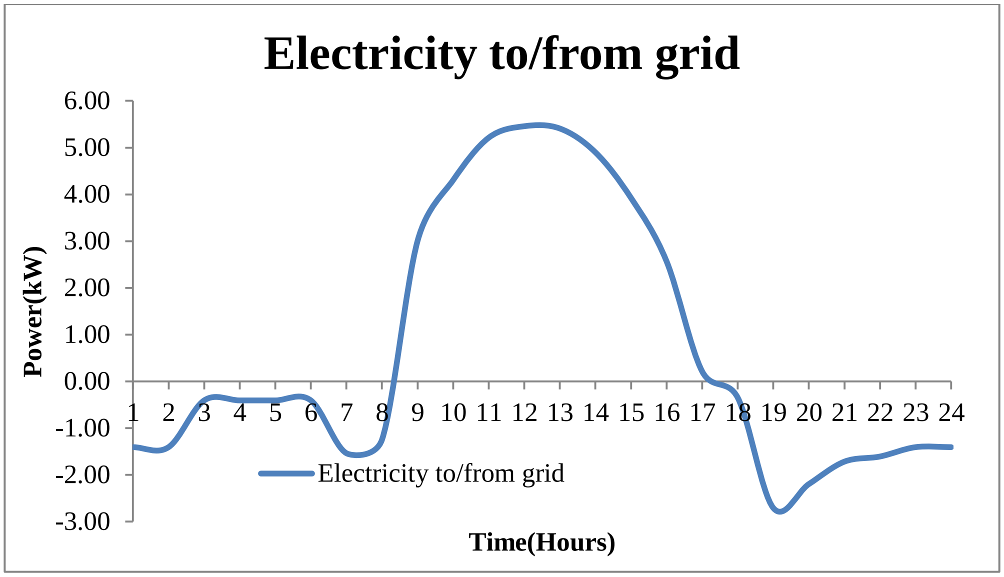


Figure 4.39: Electricity to/ from grid after PV system installed for weekend for type 3

The maximum power supplied to the grid is 5.55 kW at 12 pm for weekdays and is 5.45 kW at 12 pm for weekend whereas the power supplied from grid is 2.19 kW at 8 pm for the weekdays and weekends.

4.9 Design of PV grid tied battery system

Simulation using SAM(System Advisory Model)

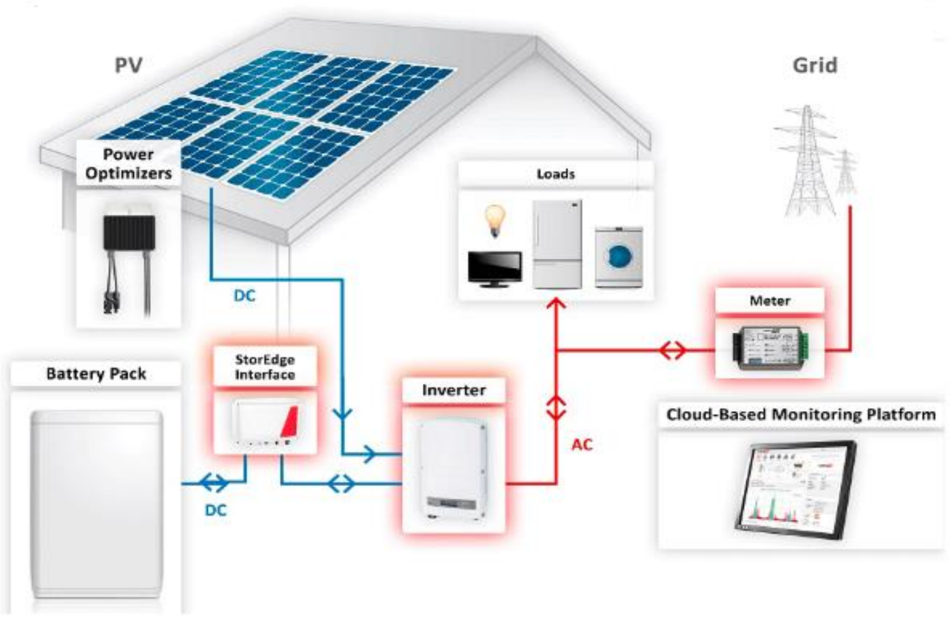


Figure 4.40: Simulation Diagram for grid tied PV with battery backup

a) <u>Design for type 1 system</u>

All designed particular is same as grid tied PV system. The only difference in battery backup design is use of suitable battery interface and selection of battery size, type.

Battery Selection:

Lithium Ion: Nickel Manganese Cobalt Oxide

Cell Capacity 2.5 Ah

Cell Voltage 3.6 V

Nominal bank capacity: 6.6 kWh(DC)

Battery maximum power: 2 kWdc

The simulation results are shown below:

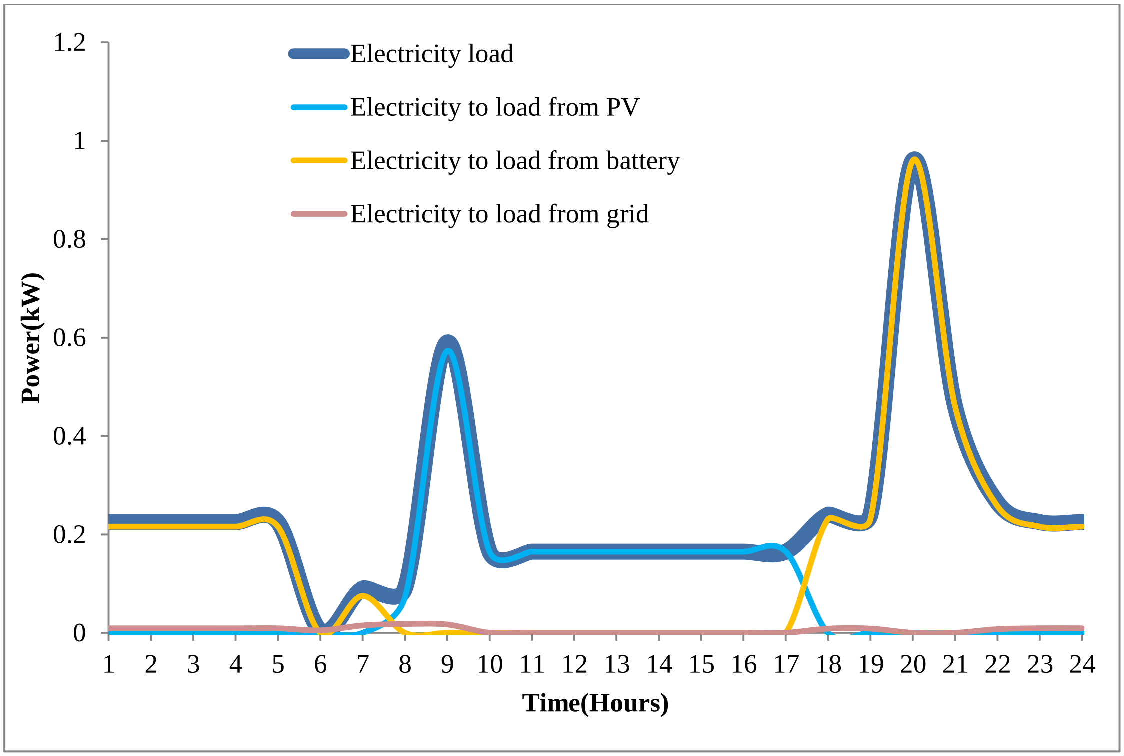


Figure 4.41: Electricity from PV to load and battery, grid to load for weekdays for type 1

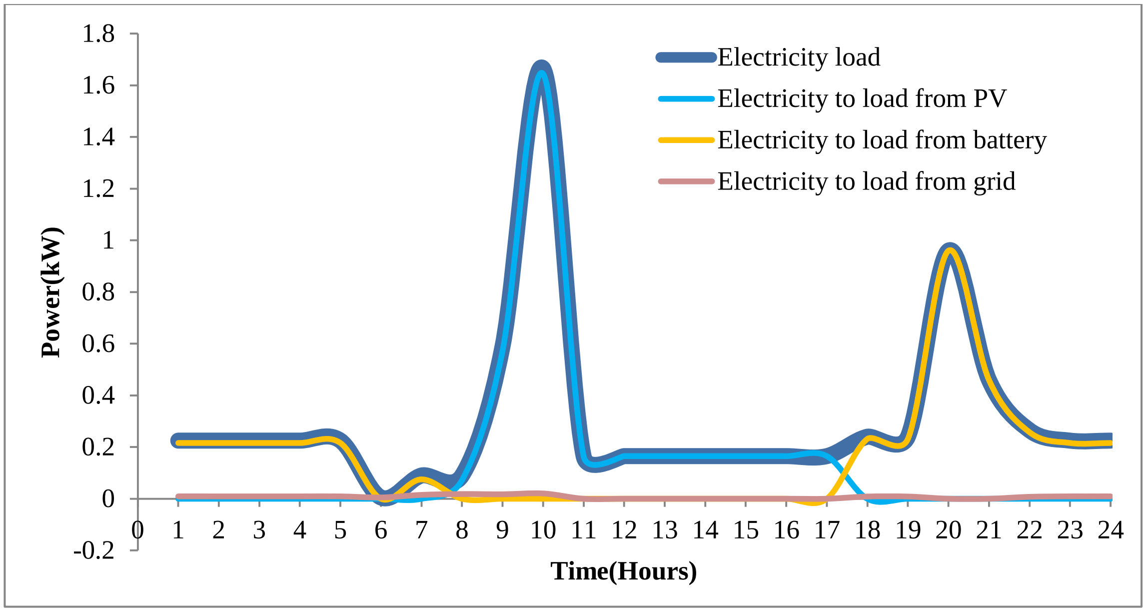


Figure 4.42: Electricity from PV to load and battery, grid to load for weekend for type 1

Here the maximum load supplied from battery is 0.95 kW at 8 pm for weekdays and weekends. The maximum load supplied from PV is 0.57 kW at 9 am for weekdays and 1.67 kW at 10 am for weekends. Since there is no solar during the night, the night load is dependent upon the battery whereas during day time when there is surplus solar the load is fed by PV. There is minimal power supply from the grid to the load.

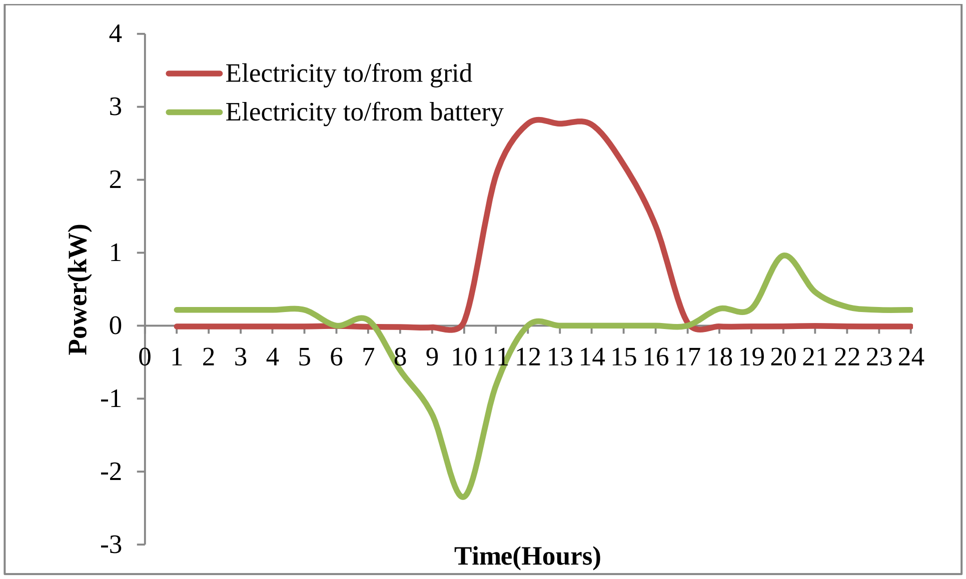


Figure 4.43: Electricity to/from grid and to/from battery for weekdays for type 1

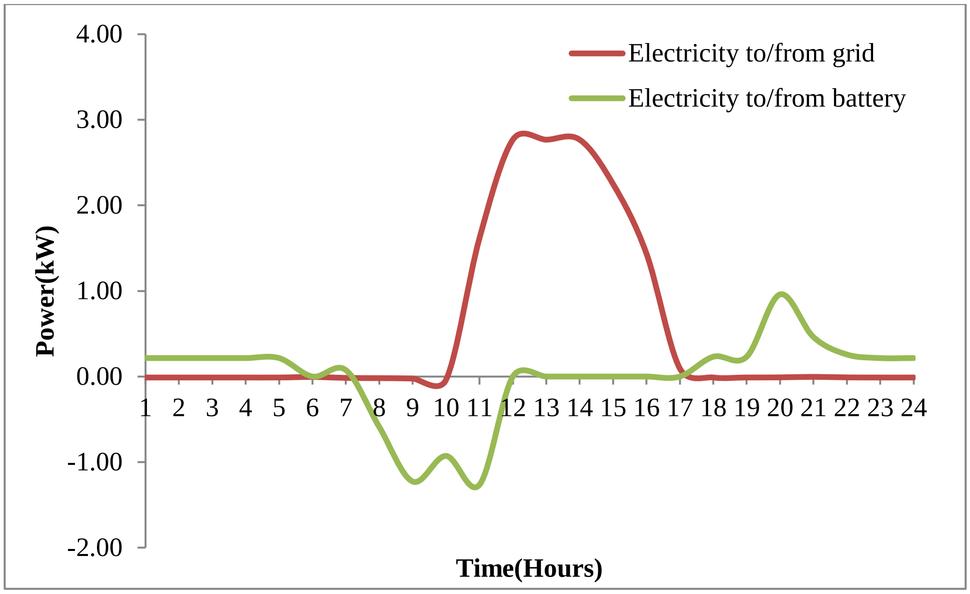


Figure 4.44: Electricity to/from grid and to/from battery for weekend for type 1

Here in the figure we can observe the electricity to/from the grid and electricity to/from battery. The maximum power supplied to the grid is 2.75 kW at 12 pm whereas the power supplied from grid minimal. The maximum power supplied from battery is 0.95kW at 8 pm for weekdays and the power supplied to battery is 2.34 kW and 1.26 kW at 10 am for weekdays and weekend. This power is used in charging the battery.

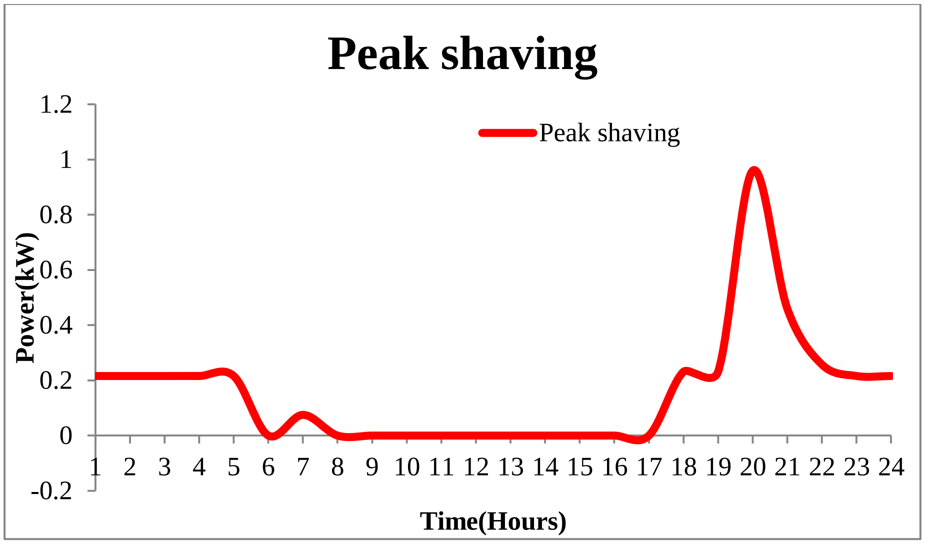


Figure 4.45: Peak shaving achieved after system installed for weekdays for type 1

Figure 4.46: Peak shaving achieved after system installed for weekend for type 1

Here in the figure we can observe the maximum peak shaving of 0.95 kW at 8 pm for weekdays and weekend. The peak shaving is the energy that is supplied by battery which when in absence of battery must be supplied from grid.

b) Design for type 2 system

All designed particular is same as grid tied PV system. The only difference in battery backup design is use of suitable battery interface and selection of battery size, type.

Battery Selection:

Lithium Ion:Nickel Manganese Cobalt Oxide

Cell Capacity 2.5 Ah

Cell Voltage 3.6 V

Nominal bank capacity: 10 kWh(DC)

Battery maximum power: 5 kWdc

The simulation results are shown below:

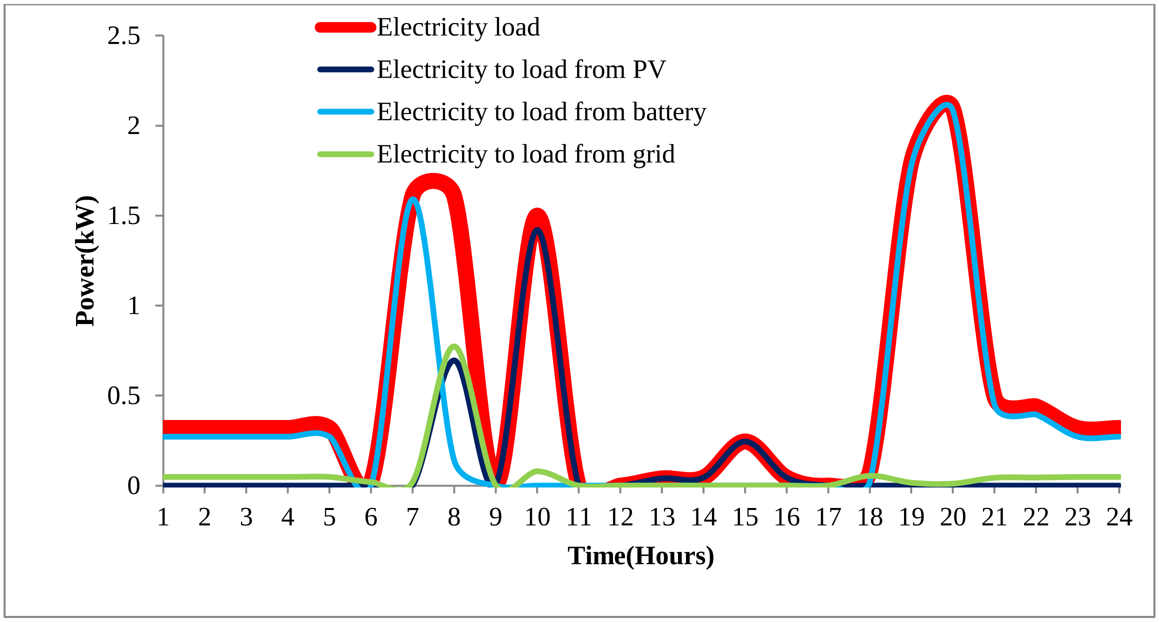


Figure 4.47: Electricity from PV to load and battery, grid to load for weekdays for type 2

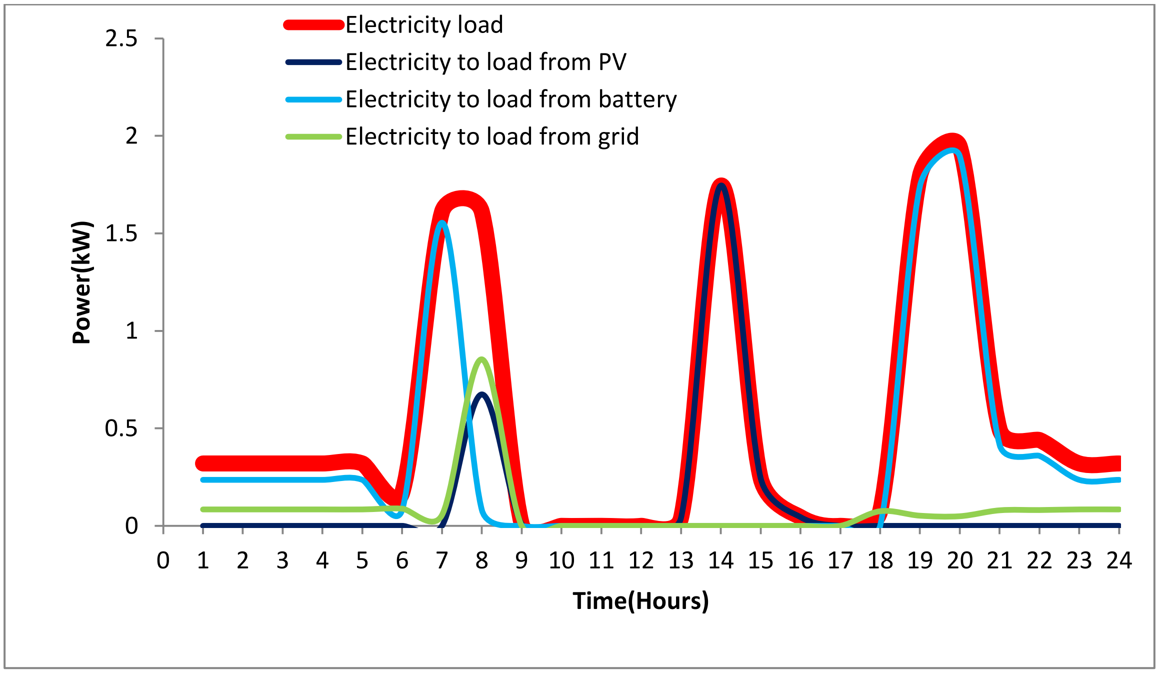


Figure 4.48: Electricity from PV to load and battery, grid to load for weekend for type 2

Here the maximum load supplied from battery is 2.08 kW and 1.89 kW at 8 pm for weekdays and weekends respectively. The maximum load supplied from PV is 1.42 kW at 10 am for weekdays and 1.74 kW at 2 pm for weekends. The maximum power supplied from grid is 0.7 kW at 8 am for weekdays and 0.8 kW at 8 am for weekends.

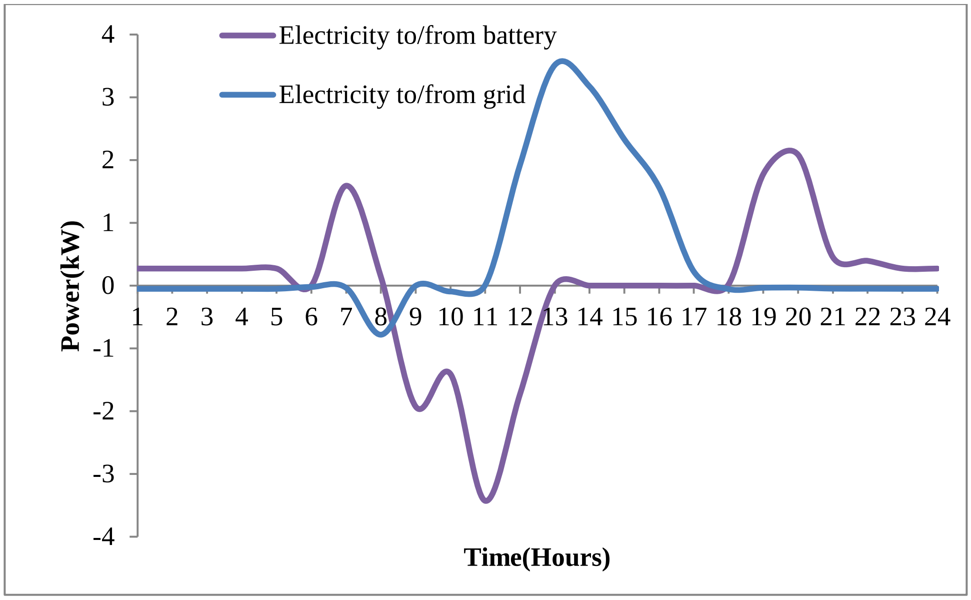


Figure 4.49: Electricity to/from grid and to/from battery for weekdays for type 2

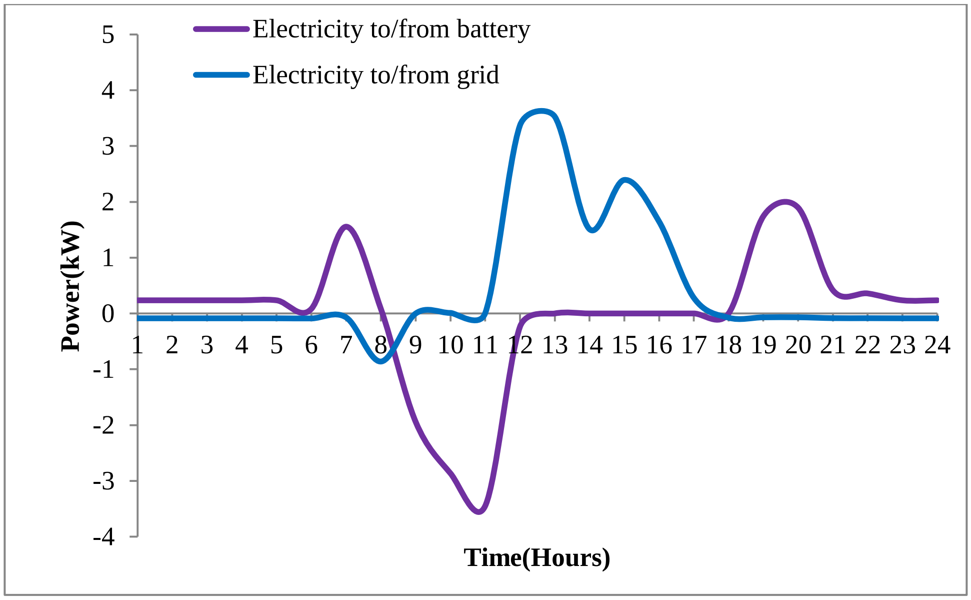


Figure 4.50: Electricity to/from grid and to/from battery for weekend of type 2

The maximum power supplied to the grid is 3.51 kW at 2 pm and whereas the power supplied from grid 0.8 kW maximum. The maximum power supplied from battery is 2.08kW and 1.89kW at 8 pm for weekdays and weekend. The power supplied to battery is 3.42 kW at 11 am for weekdays and weekend. This power is used in charging the battery.

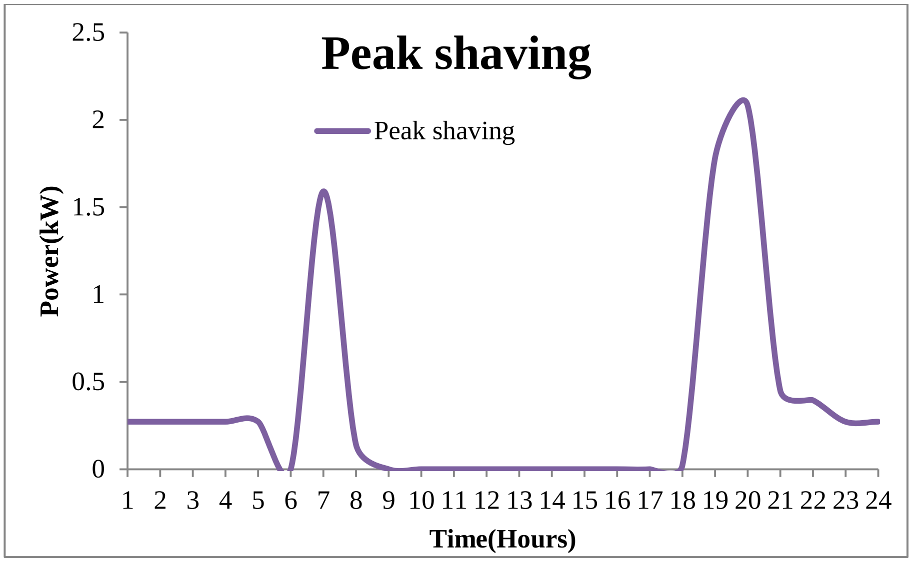


Figure 4.51: Peak shaving achieved after system installed for weekdays for type 2

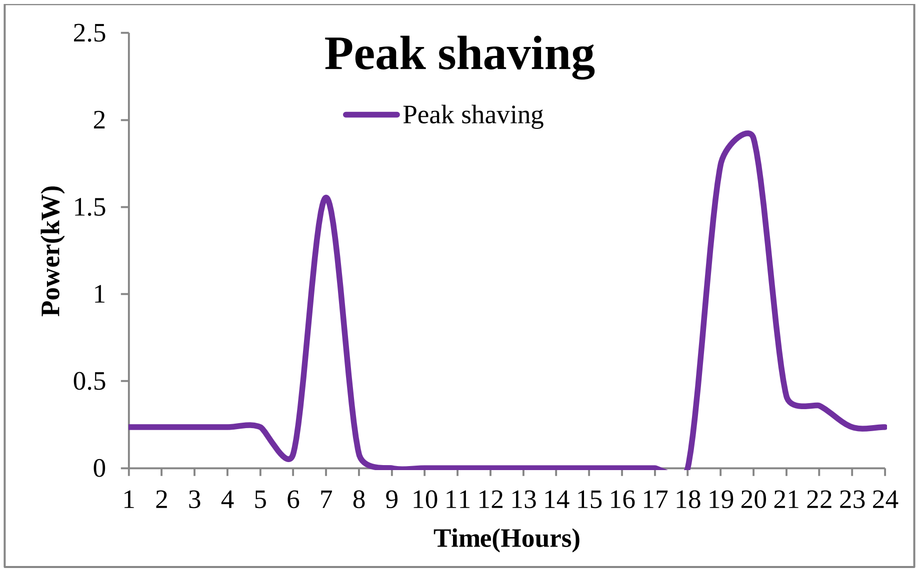


Figure 4.52: Peak shaving achieved after system installed for weekend for type 2

Here in the figure we can observe the maximum peak shaving of 2.08 kW at 8 pm for weekdays and 1.89 kW at 8 pm weekend. The peak shaving is the energy that is supplied by battery which when in absence of battery must be supplied from grid.

c) Design of type 3 system

All designed particular is same as grid tied PV system. The only difference in battery backup design is the use of suitable battery interface and selection of battery size, type.

Battery Selection:

Lithium Ion:Nickel Manganese Cobalt Oxide

Cell Capacity 2.5 Ah

Cell Voltage 3.6 V

Nominal bank capacity: 10 kWh(DC)

Battery maximum power: 5 kWdc

The simulation results are shown below:

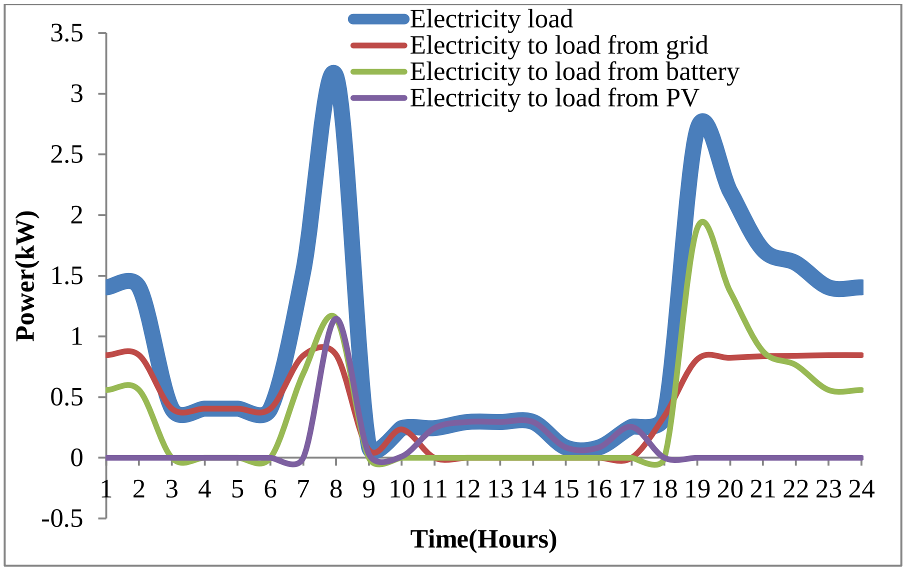


Figure 4.53: Electricity from PV to load and battery, grid to load for weekdays for type 3

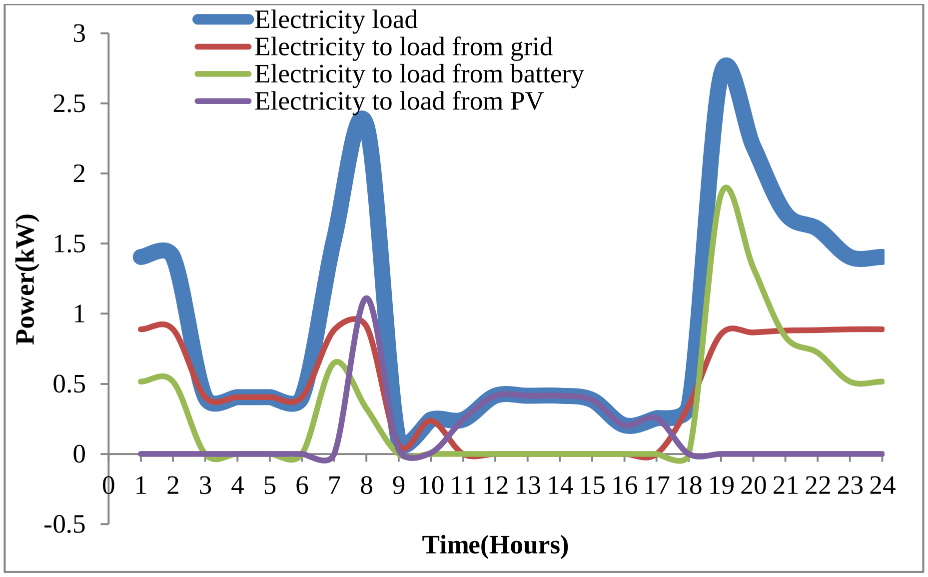


Figure 4.54: Electricity from PV to load and battery, grid to load for weekend for type 3

Here the maximum load supplied from battery is 1.89 kW and 1.85 kW at 7 pm for weekdays and weekends respectively. The maximum load supplied from PV is 1.14 kW and 1.11 kW at 8 am for weekdays and weekends respectively. The maximum power supplied from grid is 0.85 kW for charging vehicle overnight and 0.9 kW at 8 am for weekends.

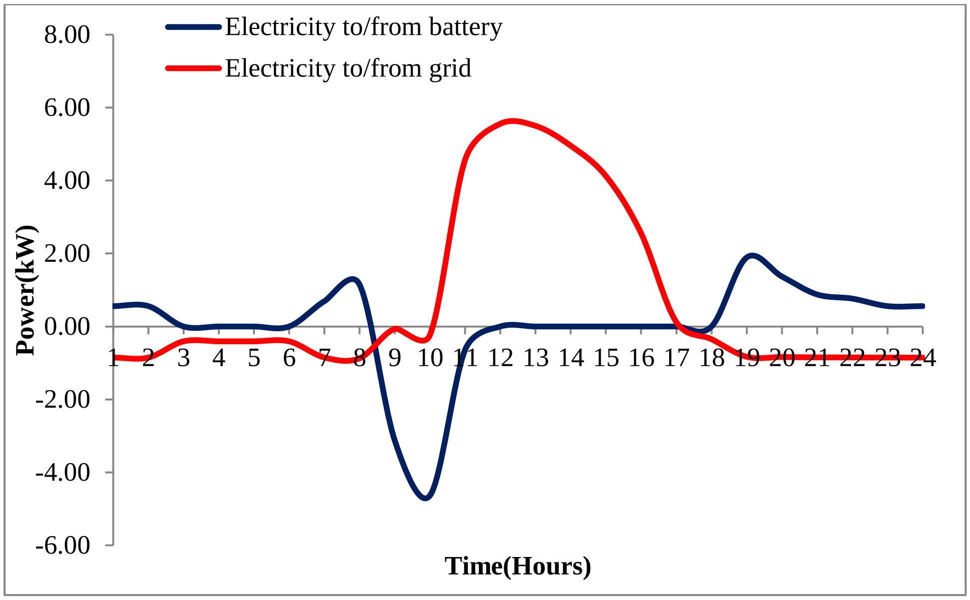


Figure 4.55: Electricity to/from grid and to/from battery for weekdays for type 3

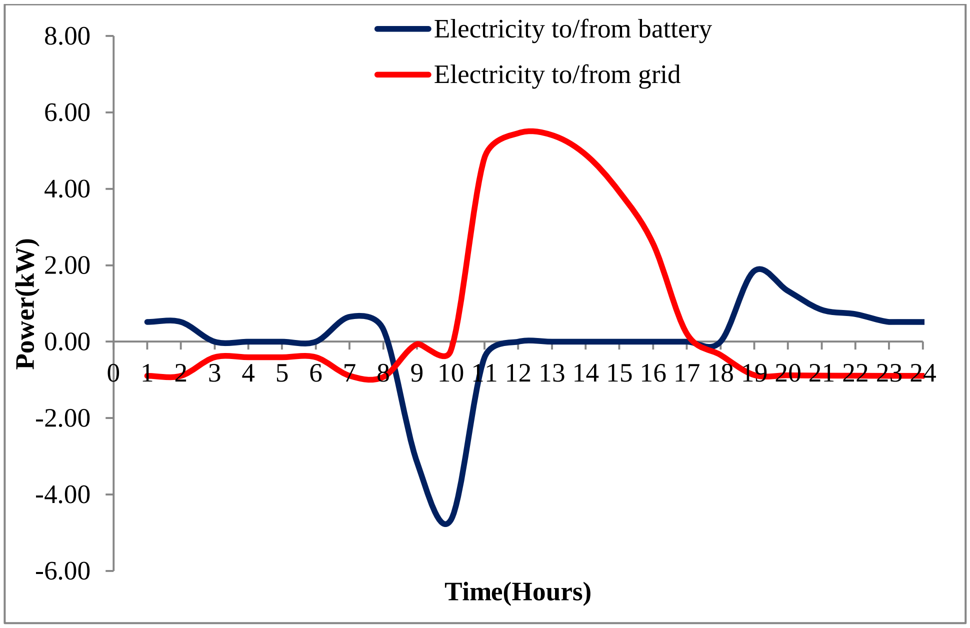


Figure 4.56: Electricity to/from grid and to/from battery for weekend for type 3

The maximum power supplied to the grid is 5.55 kW at 12 pm and whereas the power supplied from grid 0.8 kW and 0.9 maximum for weekdays and weekend respectively. The maximum power supplied from battery is 1.89 kW at 7 pm. The power supplied to battery is 4.6 kW at 10 am for weekdays and weekend. This power is used in charging the battery

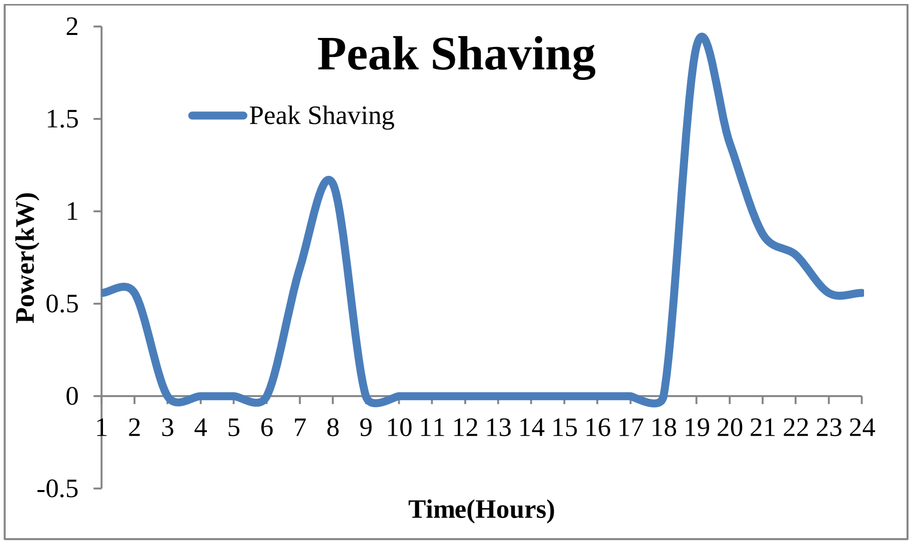


Figure 4.57: Peak Shaving achieved after system of installed for weekdays for type 3

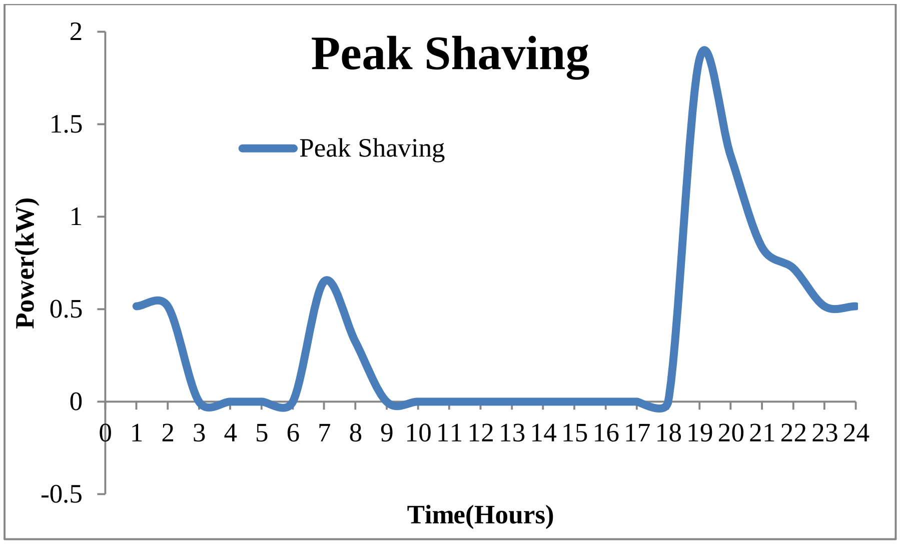


Figure 4.58: Peak shaving achieved after system installed for weekend for type 3

Here in the figure we can observe the maximum peak shaving of 1.85 kW and 1.89 kW at 7 pm for weekdays and weekend. The peak shaving is the energy that is supplied by battery which when in absence of battery must be supplied from grid.

4.10 Financial analysis for type 1

For financial evaluation following cost breakdown per unit cost is used which is extracted from the various online sites.

Table 4.9: Cost of Equipment for type 1

S.N.	Equipment	Cost($/unit)
1	Module	190
2	Inverter	1100

The cost for battery is 300 $/kWh. Therefore total cost of battery for 6.6 kWh is $1965.The battery is replaced after 10 years and inverter is replaced after 13 years.

The other cost are assumed on the per watt basis

Table 4.10: Other cost assumptions

S.N.	Equipment	Cost($/Wp)
1	Balance of system equipment	0.1
2	Installation labor	0.04
3	Installer margin and overhead	0.04
4	Engineering and developer overhead	0.01

The balance of system consist of the cost of mounting structure and other protection equipment.

The following input parameters were used for the analysis

Table 4.11: Financial input parameters

S.N.	Parameters	Values
1	Debt fraction(%)	100
2	Loan term(years)	15
3	Loan rate(%/year)	7.5
4	Analysis period(years)	25
5	Inflation rate(%/year)	4
6	Real discount rate(%/year)	6
7	Net Salvage value(% of installed cost)	10

The tariff structure used for the analysis is

Table 4.12: Tariff structure of Nepal (NEA,2019)

S.N.	Unit consumption(kWh)	30 A	
		Minimum Charge(NRs.)	Energy Charge(NRs.)
1	0-20	75	5
2	21-30	100	7
3	31-50	125	8.5
4	51-150	150	10
5	151-250	175	11
6	251-400	200	12
7	Above 400	225	13

The sell rate is 7.3 NRs/Unit which is according to the sell tariff rate provided by Ministry of Energy, Water resources and Irrigation.

The financial analysis for the type 1 House is as follows:

Table 4.13: Financial output for type 1 House

Annual energy(kWh)	6483
Capacity factor(%)	19
Energy yield(kWh/kW)	1660
Performance ratio	0.8
Nominal Levelized coe(cents/kWh)	7.03
Real Levelized coe(cents/kWh)	4.94
Electricity bill w/o system($)	254
Electricity bill with system($)	-262
Net savings with system($)	516
NPV($)	2190
Simple payback period(years)	7.4
Discounted payback period(years)	11.3
Net capital cost($)	4311.95
Debt($)	4311.95

Cost per capacity($/Wdc)	1.1
IRR(%)	14.05

The financial analysis for the type 1 House with Lithuim Ion battery is as follows:

Table 4.14: Financial output for type 1 House with Battery

Annual energy(kWh)	6415
Capacity factor(%)	18.8
Energy yield(kWh/kW)	1643
Performance ratio	0.8
Battery Efficiency(%)	92.49
Nominal Levelized coe(cents/kWh)	13.07
Real Levelized coe(cents/kWh)	9.18
Electricity bill w/o system($)	254
Electricity bill with system($)	-283
Net savings with system($)	537
NPV($)	-862
Simple payback period(years)	14.7
Discounted payback period(years)	>25
Net capital cost($)	6277.55
Debt($)	6277.55
Cost per capacity($/Wdc)	1.61
IRR(%)	6.38

4.11 Sensitivity analysis for the PV grid tied system for type 1

The sensitivity analysis is done for the various parameters

a) Debt fraction

The debt fraction the amount of debt to be invested in the system. The debt fraction considered is 100%, 70%, 50% and 0%. Considering the debt fraction the sensitivity analysis for whole of the system is done and the following result is obtained.

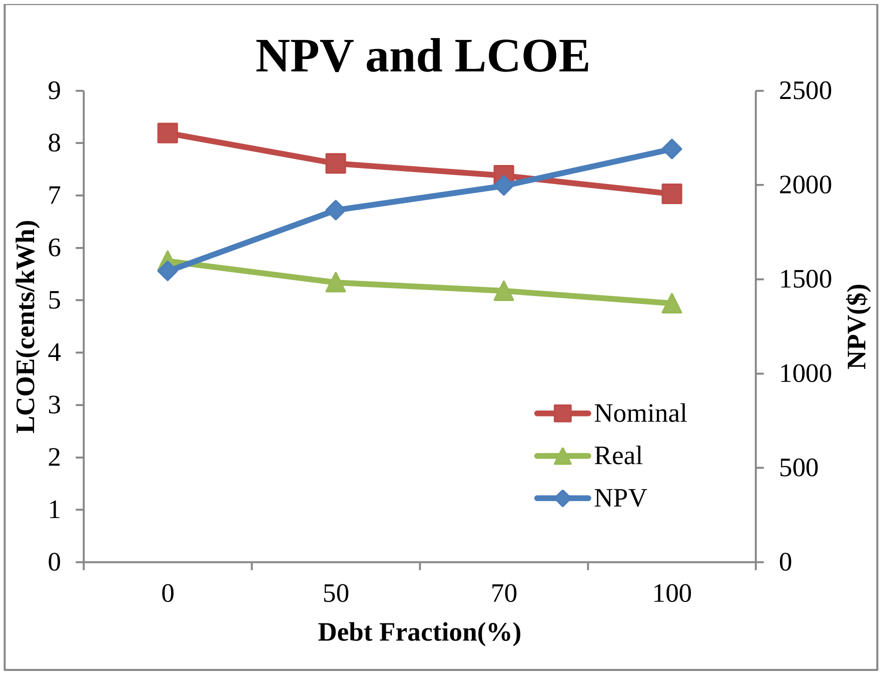


Figure 4.59: Sensitivity analysis on Debt fraction

From the above chart, it is seen that for the debt percentage of 0%, the value of 8.19 cents/ kWh nominal LCOE, 5.75 cent/kWh real LCOE and $1543 NPV is obtained. For the debt percentage of 100%, the value of 7.03 cents/ kWh nominal LCOE, 4.94 cent/kWh real LCOE and $2190 NPV is obtained. Therefore, with increase in debt percentage, the nominal and real levelised cost of electricity is decreased whereas the NPV value is increased.

b) Loan rate

The loan rate considered is 4, 6, 7.5, 8, 10 and 12. Considering the loan rate, the sensitivity analysis is done and the following result is obtained.

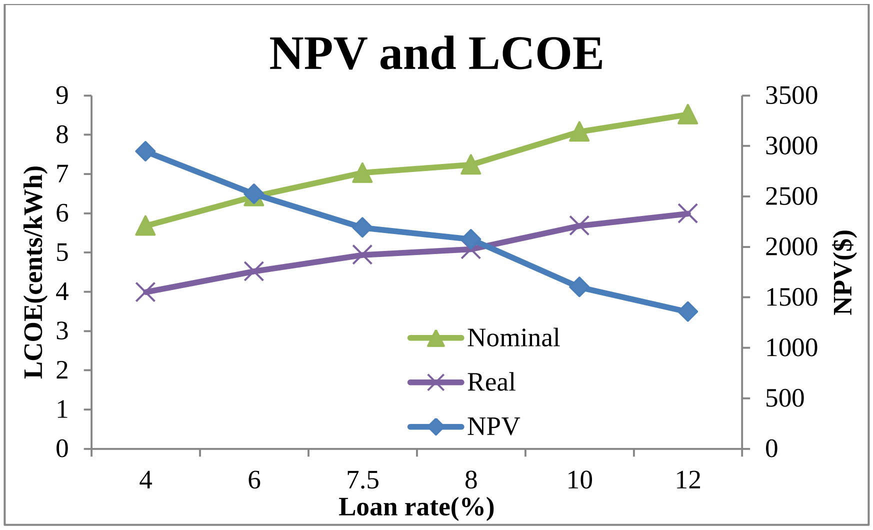


Figure 4.60: Sensitivity analysis on Loan rate

From the above chart, it is seen that for the loan rate of 4%, the value of 5.68 cents/ kWh nominal LCOE, 3.99 cent/kWh real LCOE and $2945 NPV is obtained. For the loan rate of 12%, the value of 8.52 cents/ kWh nominal LCOE, 5.99 cent/kWh real LCOE and $1356 NPV is obtained. Therefore, when the loan rate is increased, the nominal and real LCOE is increased and at the same time NPV is decreased.

c) Discount rate

The discount rate considered is 4, 6, 8, 10 and 12. Considering the discount rate the sensitivity analysis is done and the following result is obtained.

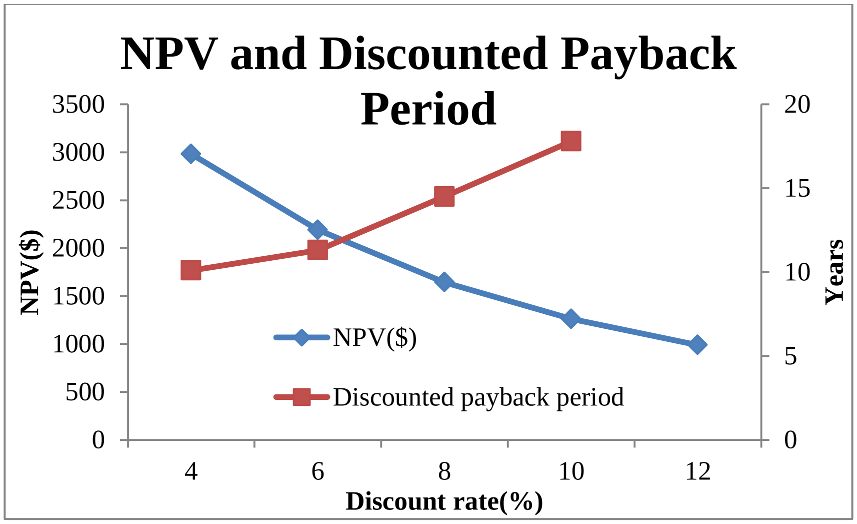


Figure 4.61: Sensitivity analysis on Discount rate

From the above chart, it is seen that for the discount rate of 4%, the value of 10.1 years discounted payback period and $2982 NPV is obtained. For the discount rate of 10%, the value of 17.8 years discounted payback period and $1261 NPV is obtained. For the discount rate 12%, the NPV value obtained is $989, but the discounted payback period is greater than 25 years so cannot be calculated. Therefore, with increase in discount rate, NPV is decreased and discounted payback period is increased.

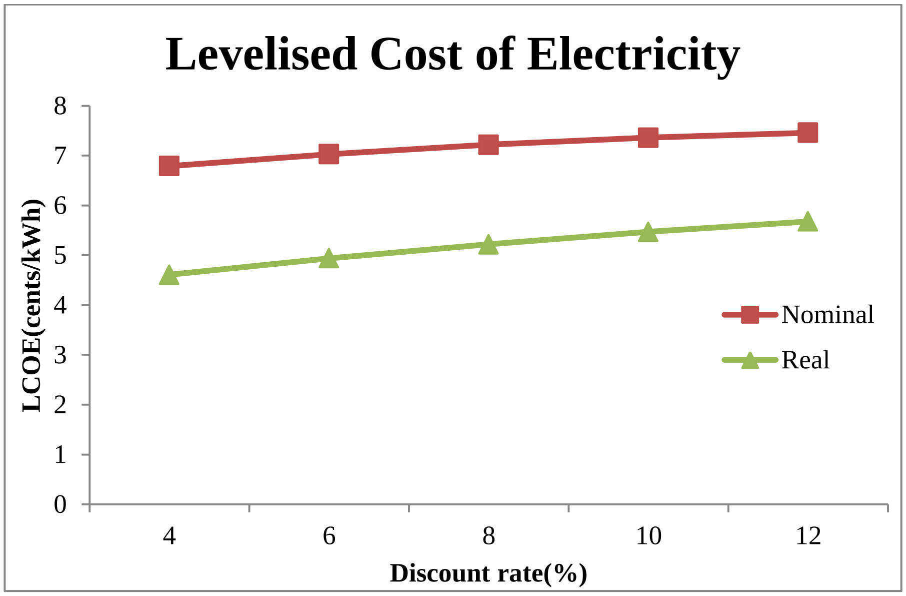


Figure 4.62: Sensitivity analysis on Discount rate

From the above chart, it is seen that for the discount rate of 4%, the value of 6.79 cents/ kWh nominal LCOE, 4.61 cent/kWh real LCOE is obtained. For the discount rate of 12%, the value of 7.46 cents/ kWh nominal LCOE, 5.68 cent/kWh real LCOE is obtained. With increase in discount rate nominal and real levelised cost of electricity is increased.

d) Solar panel cost

The solar cost considered is 0.4$/kW, 0.5$/kW, 0.6 $/kW, 0.7$/kW, 0.8$/kW. Considering the solar cost, the sensitivity analysis for whole of the system is done and the following result is obtained.

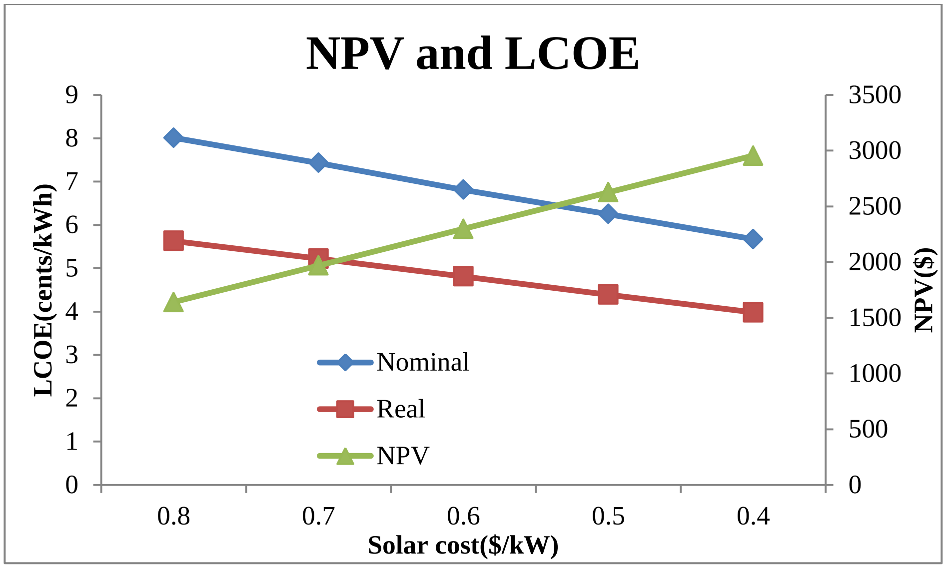


Figure 4.63: Sensitivity analysis on Solar cost

From the above chart, it is seen that for the solar panel cost of 0.8 $/kW, the value of 8.01 cents/ kWh nominal LCOE, 5.63 cents/kWh real LCOE and $1640 NPV is obtained. For the solar panel cost of 0.4 $/kW, the value of 5.67 cents/ kWh nominal LCOE, 3.98 cents/kWh real LCOE and $2954 NPV is obtained. Therefore, when the solar panel cost is decreased, the nominal and real LCOE is decreased and at the same time NPV is increased.

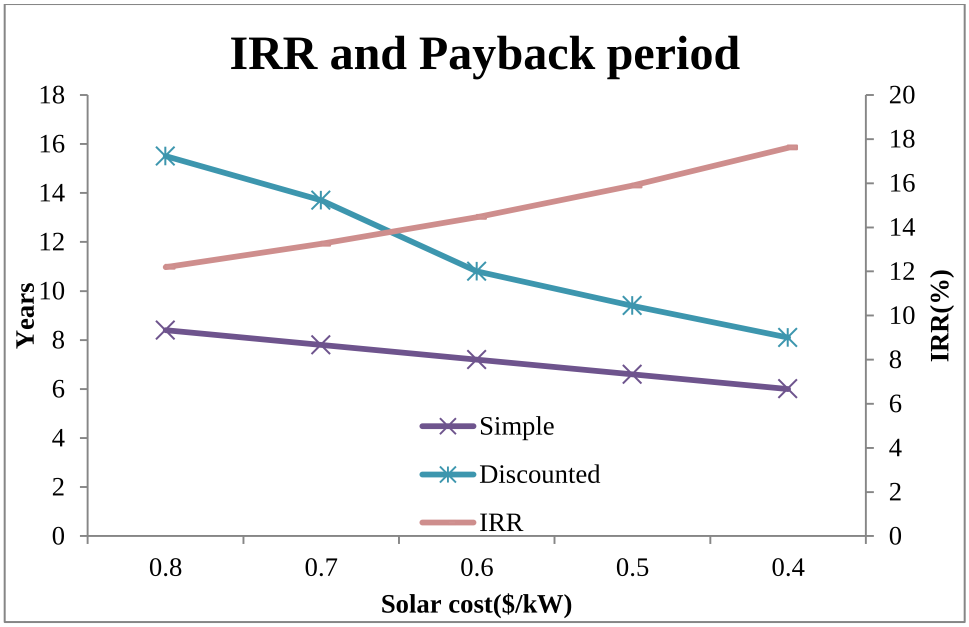


Figure 4.64: Sensitivity analysis on Solar cost

From the above chart, it is seen that for the solar panel cost of 0.8 $/kW, the value of 8.4 years simple payback period, 15.5 years discounted payback period and 12.2% IRR is obtained. For the solar panel cost of 0.4 $/kW, the value of 6 years simple payback period, 8.1 years discounted payback period and 17.61% IRR is obtained. Annually cost of panel is in decreasing trend and system has lower payback period and higher IRR.

e) Method of billing

For the billing analysis, three scenarios are considered. The first scenario is the block tariff structure which the tariff structure applied to the residential sector by NEA. The next scenario is the Time of Day tariff structure. Since this type of tariff structure is not applicable in the residential sector, so the tariff structure of the commercial sector for the 11 kV consumers is applied. For the average billing, the maximum units consumable for the type 1 system is considered. For the type 1 system, maximum units consumable is 186 units monthly which lies in between 151-200 units, therefore the billing done is minimum charge of Rs. 175 and per unit charge of Rs. 11.

Table 4.15: ToD Tariff Structure

Baisakh to Mangsir(May-November)				
Consumer category	Demand charge Rs. kVA/month	Peak Time (17:00-23:00)	Off Peak Time (23:00-5:00)	Normal Time (5:00-17:00)
Commercial	315	12.6	6.9	11.1
Poush to Chaitra(December-April)				
Consumer category	Demand charge Rs. kVA/month	Peak Time (17:00-23:00)	Normal Time (23:00-17:00)	
Commercial	315	12.30	10.80	

The result obtained is

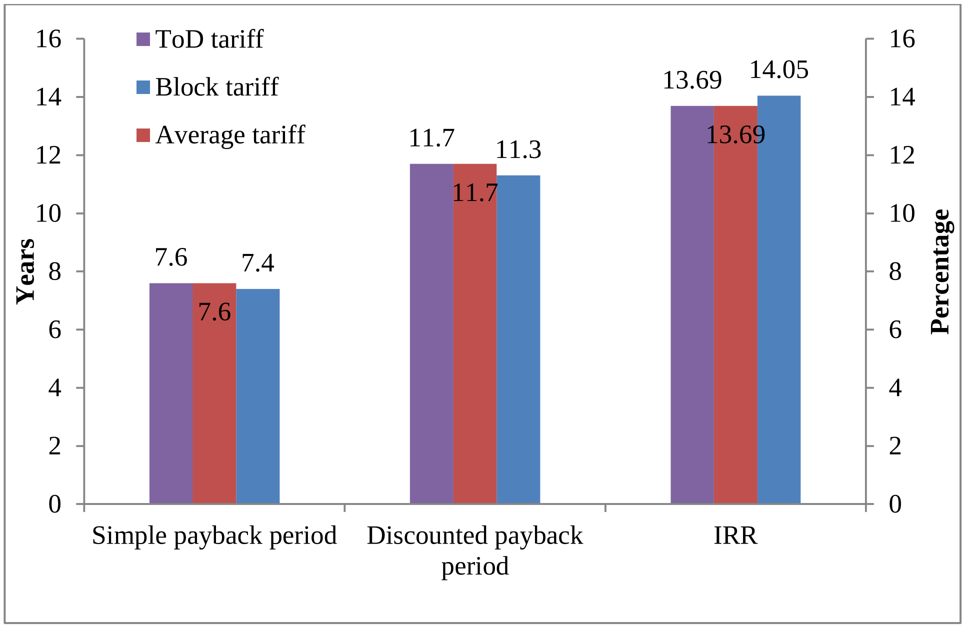


Figure 4.65: Comparison chart for Method of Billing

From the above graph, it is seen that the simple payback period, discounted payback period and IRR is obtained same value for the ToD tariff and average tariff whereas for the block rate tariff simple and discounted payback period is less and IRR is more compared to the two tariffs.

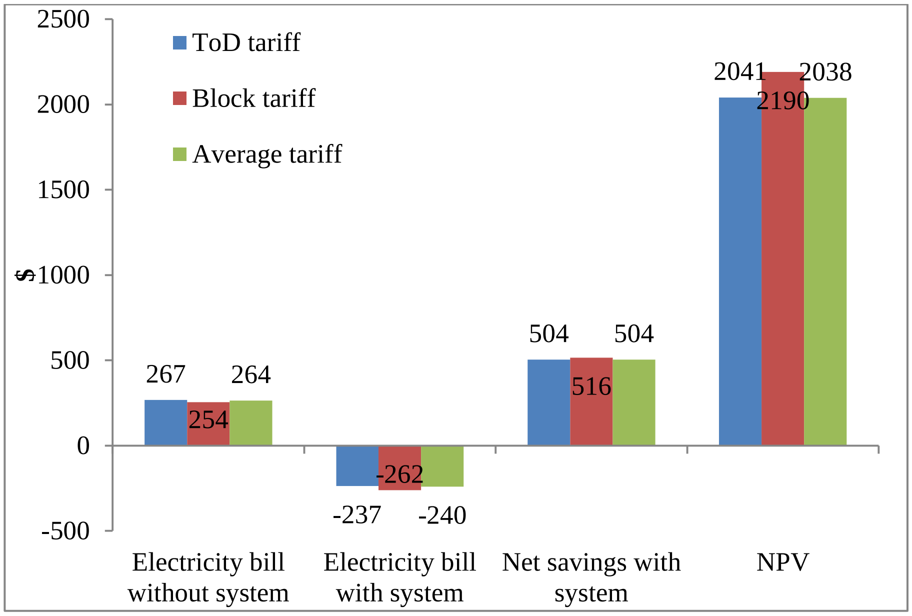


Figure 4.66: Comparison chart for Method of Billing

From the graph above it is seen that, the net savings from the ToD tariff and average tariff is same whereas the electricity bill with system is lowest for ToD tariff and more for average billing. The net savings with system is maximum for block tariff. In the same way, NPV value is highest for the block rate compared to the two tariff structure. Hence the ToD tariff and average tariff seems less beneficial for the residential sector compared to the block tariff structure.

f) Type of PPA rate

For the PPA rate, two scenarios are considered. The hydropower PPA rate is considered for the first scenario in which the summer PPA and winter PPA rate are fed excluding the escalation percentage. For the net metering scenario, the feed in tariff of NRs. 7.30 is considered without the seasonal PPA rate.

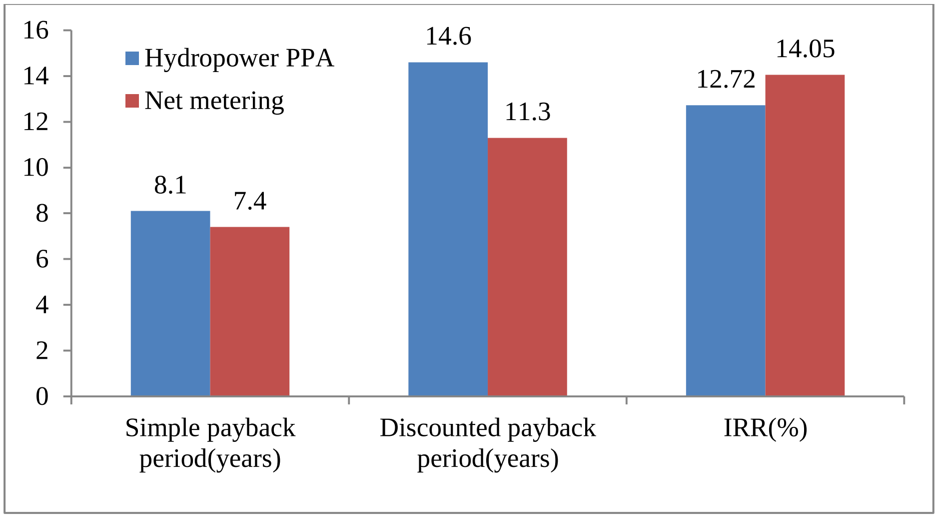


Figure 4.67: Comparison chart for different type of PPA rate

From the above graph, it is seen that the simple payback period, discounted payback period obtained for the hydropower PPA rate is higher compared to the net metering tariff rate of NRs. 7.3. The IRR rate is lower for hydropower PPA compared to net metering tariff rate.

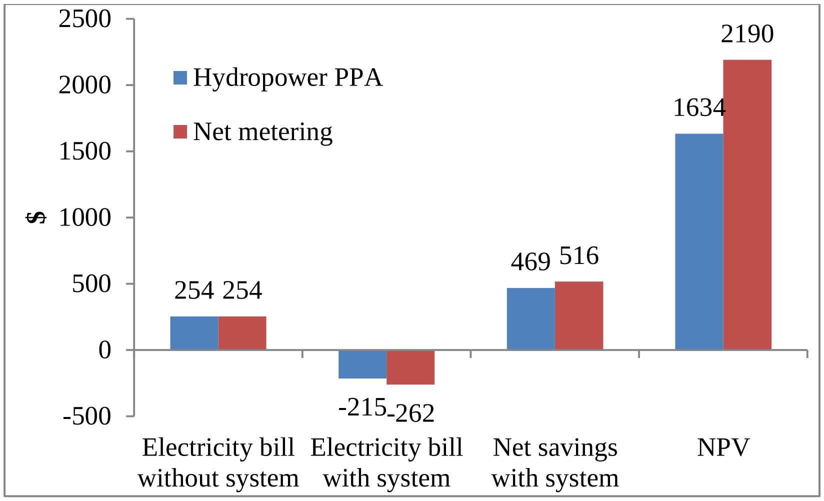


Figure 4.68: Comparison chart for type of PPA rate

From the graph above it is seen that, the net savings from the hydropower PPA tariff is low compared to the net metering tariff. In the same way, the NPV value for hydropower PPA tariff is low compared to the net metering tariff. Therefore, the net metering rate is more beneficial compared to hydropower PPA rate.

4.12 Sensitivity analysis for PV grid tied with battery system for type 1

The sensitivity analysis is done for the various parameters

a) Debt fraction

The debt fraction considered is 100%, 70%, 50% and 0%. Considering the debt fraction the following results is obtained.

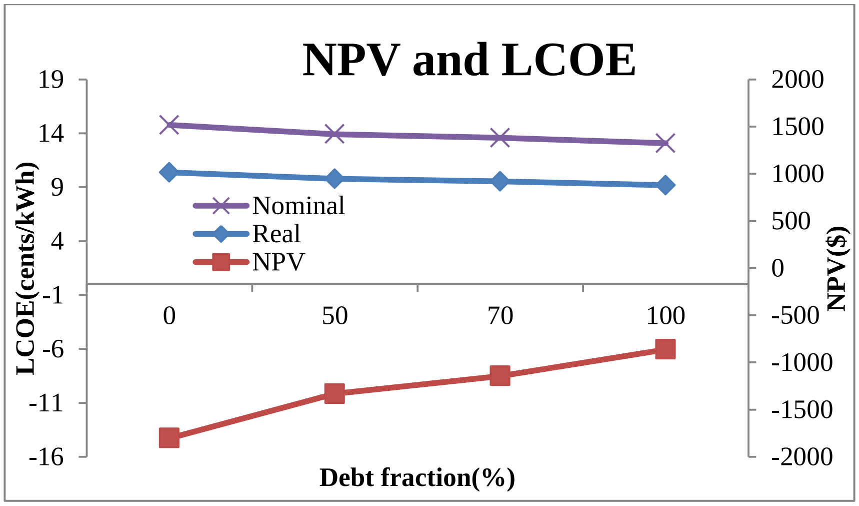


Figure 4.69: Sensitivity analysis on Debt fraction

From the above chart, it is seen that for the debt percentage of 0%, the value of 14.77 cents/ kWh nominal LCOE, 10.38 cent/kWh real LCOE and $-1803 NPV is obtained. For the debt percentage of 100%, the value of 13.07 cents/ kWh nominal LCOE, 9.18 cent/kWh real LCOE and $-862 NPV is obtained. Therefore, with increase in debt percentage, the nominal and real levelised cost of electricity is decreased whereas the NPV value is increased.

b) Loan rate

The loan rate considered is 4, 6, 7.5, 8, 10, 12. Considering the debt fraction the following results is obtained.

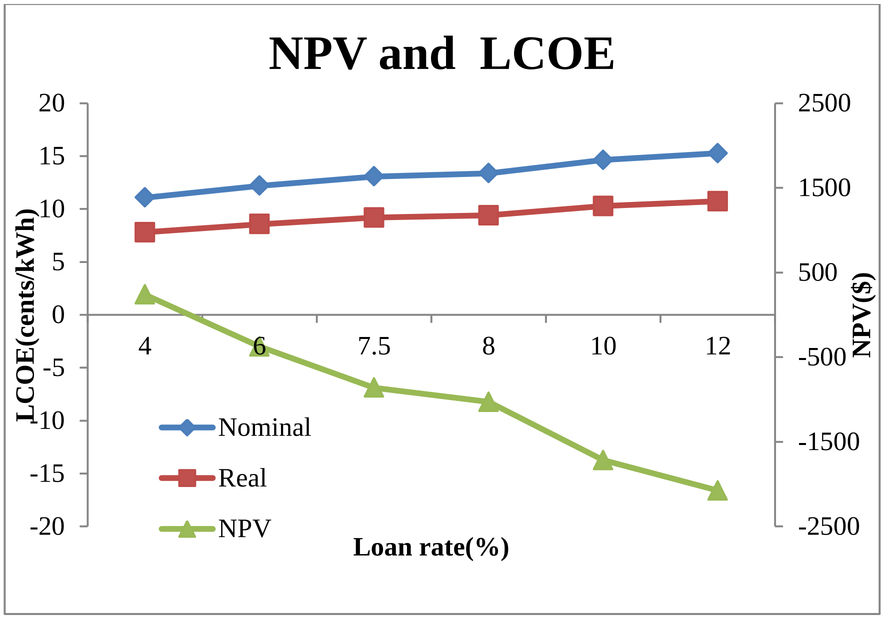


Figure 4.70: Sensitivity analysis on Loan rate

From the above chart, it is seen that for the loan rate of 4%, the value of 11.08 cents/ kWh nominal LCOE, 7.79 cent/kWh real LCOE and $238 NPV is obtained. For the loan rate of 12%, the value of 15.26 cents/ kWh nominal LCOE, 10.72 cent/kWh real LCOE and $-2076 NPV is obtained. Therefore, when the loan rate is increased, the nominal and real LCOE is increased and at the same time NPV is decreased. It can be observed that the NPV value is changed from positive value to negative value for loan rate 4% and 6%. But the actual loan rate provided by the bank is far beyond this value. So for the system to be feasible it must be heavily subsidized.

c) Discount rate

The discount rate considered is 4, 6, 8, 10, 12. Considering the discount rate the following results is obtained.

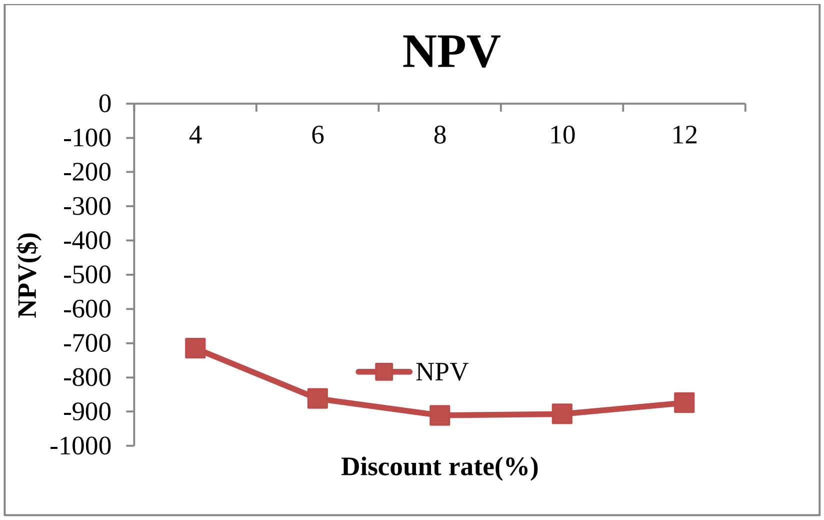


Figure 4.71: Sensitivity analysis on Discount rate

From the above chart, it is seen that for the discount rate of 4%, the value of $-715 NPV is obtained. For the discount rate 12%, the NPV value obtained is $-874, but the discounted payback period is greater than 25 years for all discount rate. Therefore, with increase in discount rate, NPV is decreased and discounted payback period is not calculated.

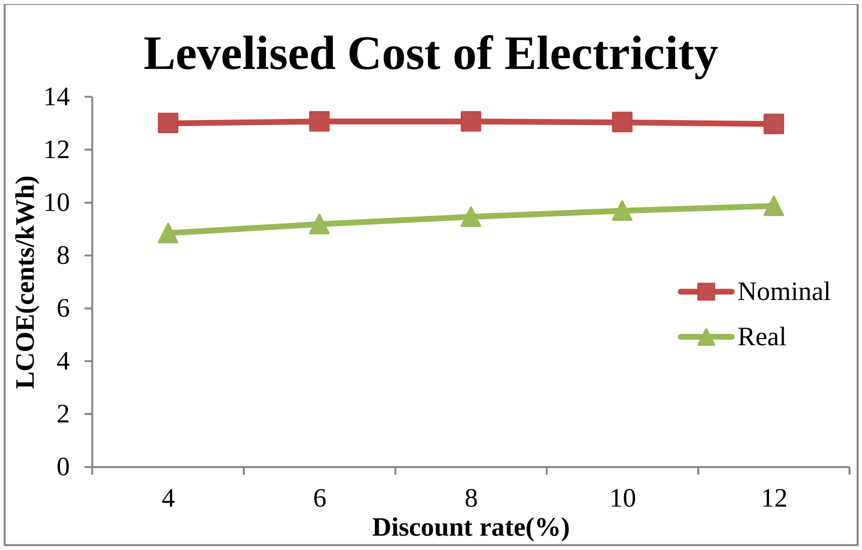


Figure 4.72: Sensitivity analysis on Discount rate

From the above chart, it is seen that for the discount rate of 4%, the value of 13 cents/ kWh nominal LCOE, 8.84 cents/kWh real LCOE is obtained. For the discount rate of 12%, the value of 12.97 cents/ kWh nominal LCOE, 9.87 cents/kWh real LCOE is obtained. With increase in discount rate nominal and real levelised cost of electricity is increased.

d) Solar panel cost

The solar cost considered is 0.4$/kW, 0.5$/kW, 0.6 $/kW, 0.7$/kW, 0.8$/kW. Considering the solar cost, the sensitivity analysis for whole of the system is done and the following result is obtained.

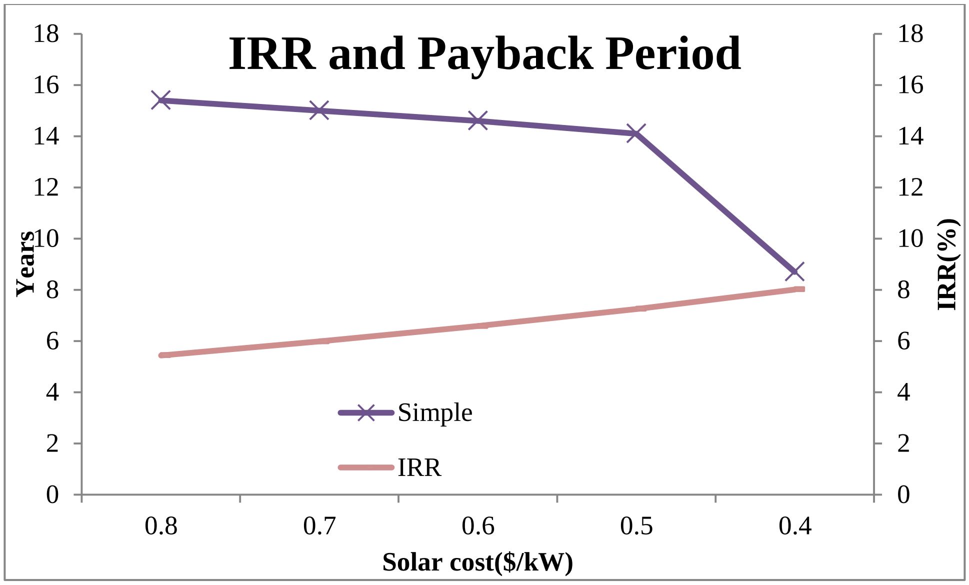


Figure 4.73: Sensitivity analysis on solar cost

From the above chart, it is seen that for the solar panel cost of 0.8 $/kW, the value of 15.4 years simple payback period and 5.44% IRR is obtained. For the solar panel cost of 0.4 $/kW, the value of 8.7 years simple payback period and 8.01% IRR is obtained. Annually cost of panel is in decreasing trend and system have lower payback period and higher IRR. It is seen from the chart that for the panel cost of 0.5 $/kW and 0.4 $/kW, there is drastic change in the payback period. It is because the payback period neglected the replacement cost after the positive payback period is obtained.

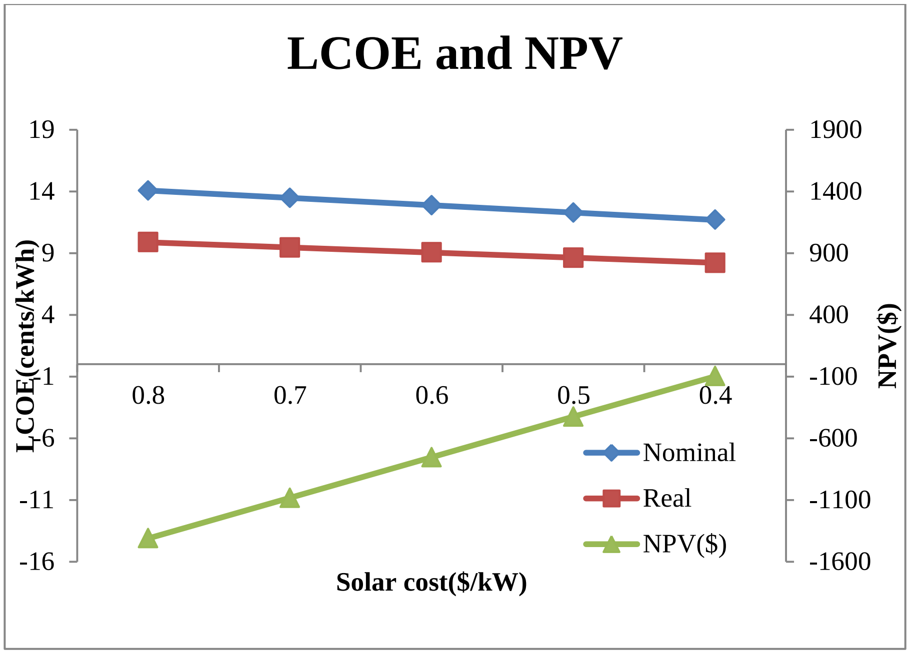


Figure 4.74: Sensitivity analysis on Solar cost

From the above chart, it is seen that for the solar panel cost of 0.8 $/kW, the value of 14.06 cents/ kWh nominal LCOE, 9.88 cents/kWh real LCOE and $-1412 NPV is obtained. For the solar panel cost of 0.4 $/kW, the value of 11.69 cents/ kWh nominal LCOE, 8.21 cents/kWh real LCOE and $-98 NPV is obtained. Therefore, when the solar panel cost is decreased, the nominal and real LCOE is decreased and at the same time NPV is increased but the positive NPV is never obtained.

e) Method of billing

For the billing analysis, three scenarios is considered. The scenarios are the block tariff structure, ToD tariff structure and average billing.

The result obtained is

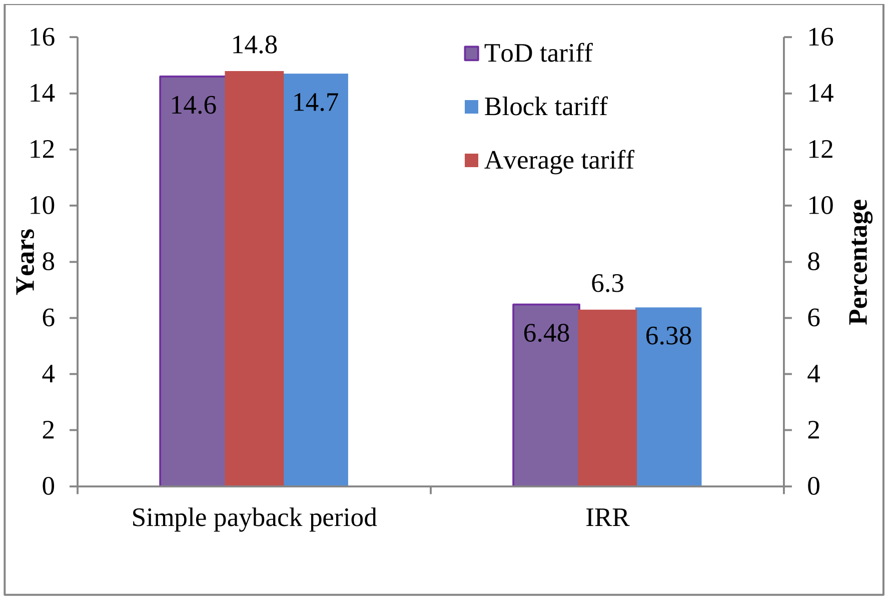


Figure 4.75: Comparison chart for Method of Billing

From the above graph, it is seen that the simple payback period for the ToD tariff is low compared to block tariff and average tariff. The IRR is obtained is also high for ToD tariff compared to the other two tariff structure. This is because during the peak time the battery supplied the load hence reducing the consumption pattern for the peak time and cost of supply for the same load.

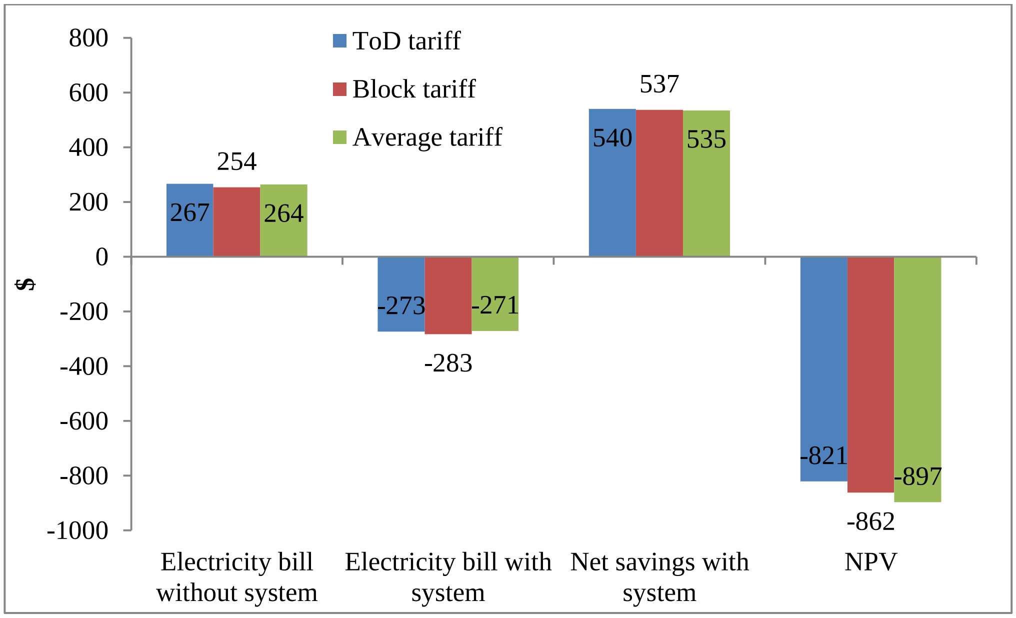


Figure 4.76: Comparison chart for Method of Billing

From the above graph, it is seen that the net savings for the ToD tariff is more compared to block tariff and average tariff. The electricity bill without system for block tariff is low compared to the other system and the electricity bill with system is more for the same tariff structure. The NPV obtained is low for the ToD tariff structure. Therefore, for the battery system if the ToD tariff is modified for the residential sector, it is advantageous for the residential sector.

f) Type of PPA rate

For the PPA rate, two scenario is considered. The hydropower PPA rate is considered for the first scenario and the other is net metering tariff.

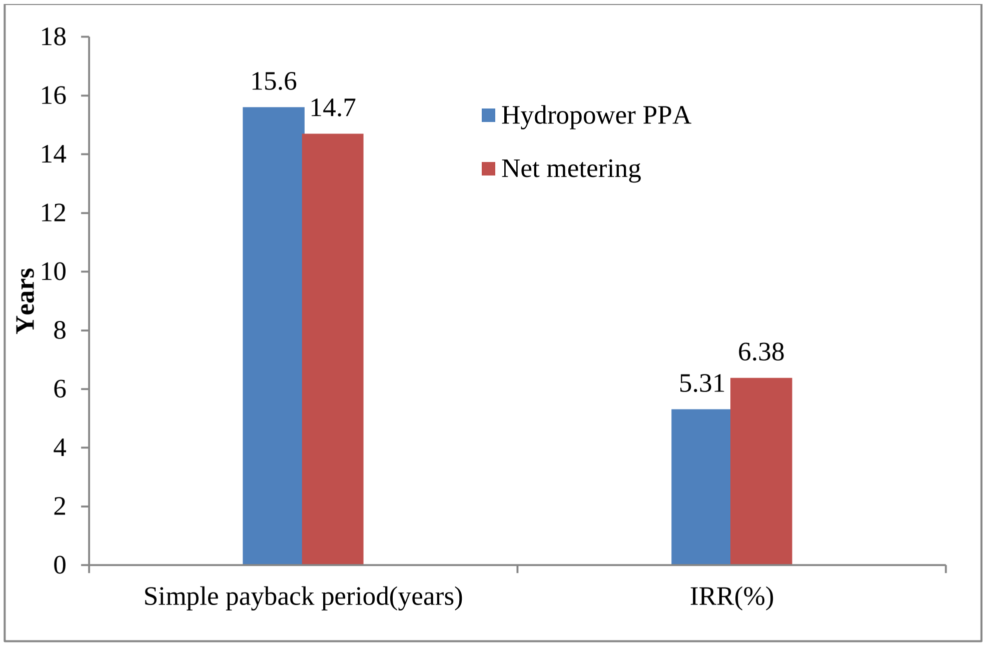


Figure 4.77: Comparison chart for type of PPA rate

From the above graph, it is seen that the simple payback period obtained for the hydropower PPA rate is higher compared to the net metering tariff rate of NRs. 7.3. The IRR rate is lower for hydropower PPA compared to net metering tariff rate.

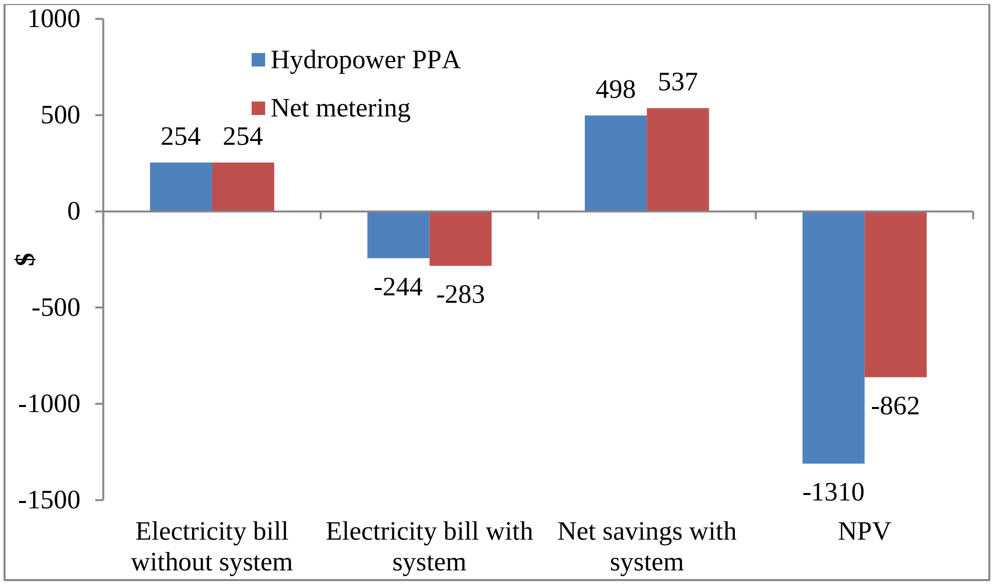


Figure 4.78: Comparison chart for type of PPA rate

From the graph above it is seen that, the net savings from the hydropower PPA tariff is low compared to the net metering tariff. In the same way, the NPV value for hydropower PPA tariff is low compared to the net metering tariff. Therefore, the net metering rate is more beneficial compared to hydropower PPA rate.

4.13 Comparison of grid tied system with and without battery for type 1

The grid tied system with and without battery is plotted, compared and analyzed in this section.

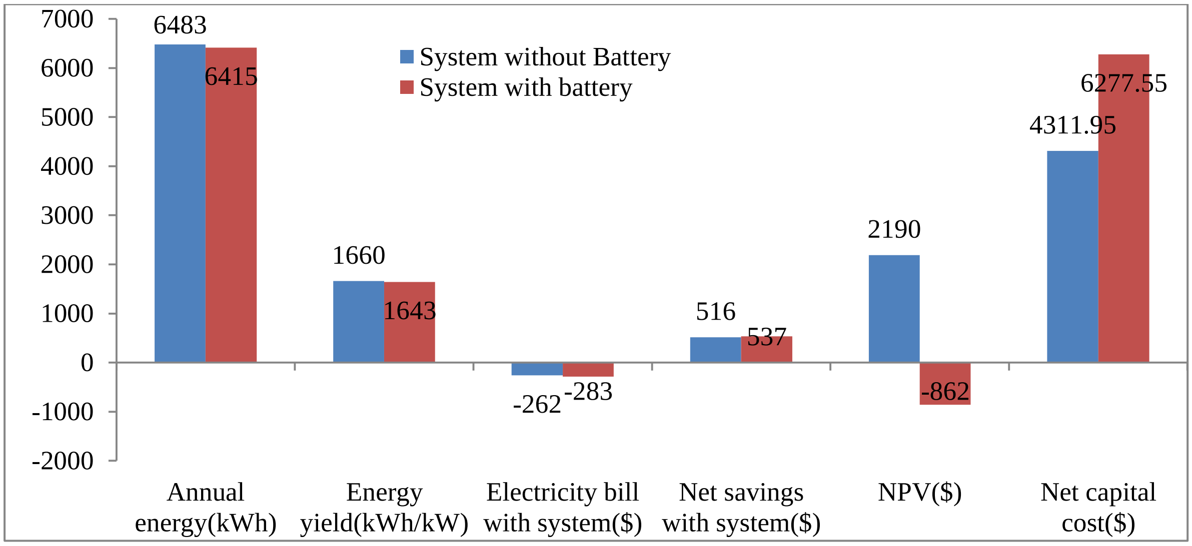


Figure 4.79: Comparison chart between two systems

In the above figure, the system without battery has higher annual energy compare to the one with battery because there is certain percentage loss in battery. The system without battery has positive NPV and with battery has negative NPV. As the net capital cost include the battery cost therefore the net capital cost for the system with battery is high.

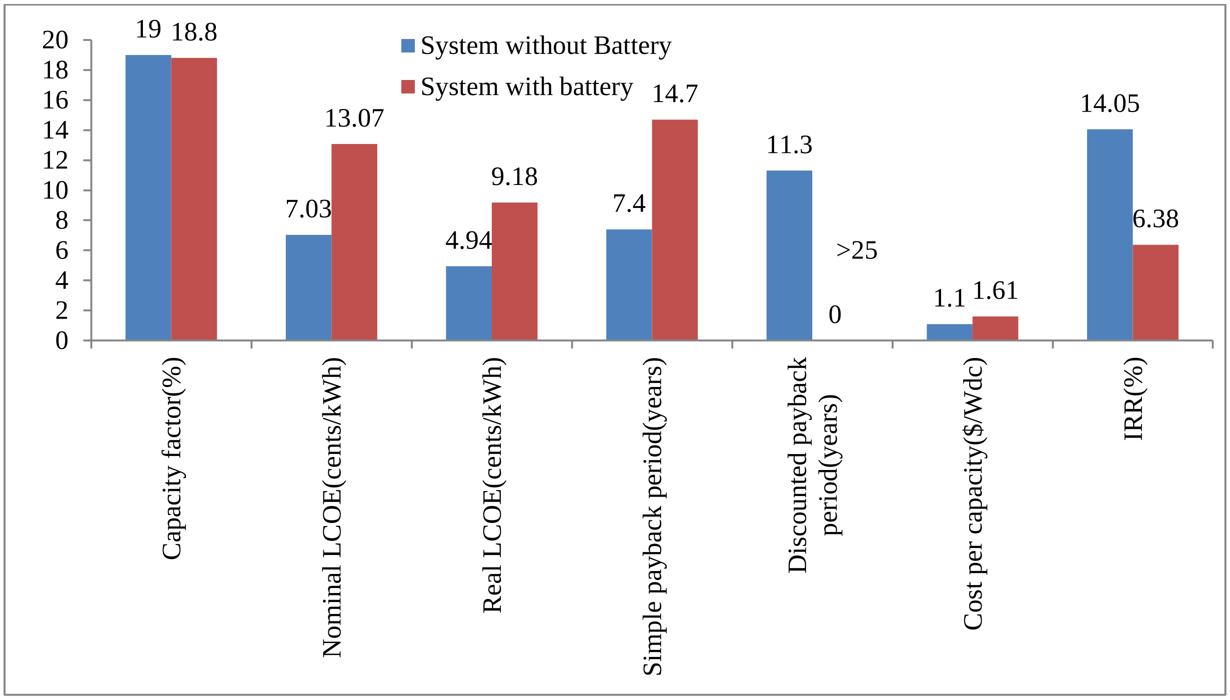


Figure 4.80: Comparison chart between two systems

In the above figure, the system without battery has higher IRR, lower Payback period, lower LCOE. Due to high cost of battery and replacement required after certain years, the system is highly capital intensive. But if the ToD tariff is applicable during the peak time for the system with battery, this system can give certain benefits but for that the cost of battery should decrease drastically.

4.14 Financial analysis for type 2

For financial evaluation, all the parameters are same as type 1 system, the only cost difference is inverter cost, since the size of inverter is different than type 1 system. The inverter cost is 1400 $/unit. The cost for battery is 300 $/kWh. Therefore total cost of battery for 10 kWh is $2986.

The financial analysis for the type 2 House is as follows:

Table 4.16: Financial output for type 2 House

Annual energy(kWh)	7812
Capacity factor(%)	18.6
Energy yield(kWh/kW)	1625
Performance ratio	0.8
Nominal Levelized coe(cents/kWh)	7.3
Real Levelized coe(cents/kWh)	5.13
Electricity bill w/o system($)	554
Electricity bill with system($)	-81
Net savings with system($)	635
NPV($)	2585
Simple payback period(years)	7.5
Discounted payback period(years)	11.5
Net capital cost($)	5353.16
Debt($)	5353.16
Cost per capacity($/Wdc)	1.11
IRR(%)	14.05

The financial analysis for the Type 2 House with Lithuim Ion battery is as follows:

Table 4.17: Financial output for Type 2 House with Battery

Annual energy(kWh)	7722
Capacity factor(%)	18.3
Energy yield(kWh/kW)	1607
Performance ratio	0.79
Battery Efficiency(%)	93.59
Nominal Levelized coe(cents/kWh)	14.8
Real Levelized coe(cents/kWh)	10.4
Electricity bill w/o system($)	554
Electricity bill with system($)	-191
Net savings with system($)	745

NPV($)	-1188
Simple payback period(years)	14.6
Discounted payback period(years)	>25
Net capital cost($)	8339.37
Debt($)	8339.37
Cost per capacity($/Wdc)	1.74
IRR(%)	6.23

4.15 Financial analysis for type 3

For financial evaluation, all the parameters are same as type 1 system, the only cost difference is inverter and battery cost. The inverter cost is 2200 $/unit. The cost for battery is 300 $/kWh. Therefore total cost of battery for 10 kWh is $2986.

The financial analysis for the type 3 House is as follows:

Table 4.18: Financial output for type 3 House

Annual energy(kWh)	12781
Capacity factor(%)	18.7
Energy yield(kWh/kW)	1636
Performance ratio	0.8
Nominal Levelized coe(cents/kWh)	6.89
Real Levelized coe(cents/kWh)	4.84
Electricity bill w/o system($)	1035
Electricity bill with system($)	17
Net savings with system($)	1018
NPV($)	4429
Simple payback period(years)	7.5
Discounted payback period(years)	11.6
Net capital cost($)	8623.89
Debt($)	8623.89
Cost per capacity($/Wdc)	1.10
IRR(%)	14.07

The financial analysis for the type 3 House with Lithuim Ion battery is as follows:

Table 4.19: Financial output for type 3 House with Battery

Annual energy(kWh)	12692
Capacity factor(%)	18.6
Energy yield(kWh/kW)	1625
Performance ratio	0.8
Battery Efficiency(%)	94.33
Nominal Levelized coe(cents/kWh)	11.52
Real Levelized coe(cents/kWh)	8.1
Electricity bill w/o system($)	1035
Electricity bill with system($)	-123
Net savings with system($)	1158
NPV($)	628
Simple payback period(years)	11.7
Discounted payback period(years)	>25
Net capital cost($)	11610.10
Debt($)	11610.10
Cost per capacity($/Wdc)	1.49
IRR(%)	9.05

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The finding of this thesis is obtained from the survey conveyed in 20 houses out of 51 of Star Homes, situated at 27°42'29.35"N latitude and 85°16'49.56"E longitude. It has total of 51 numbers of buildings. There are three categories of building i.e. type 1(small buildings)-4 numbers, type 2(medium buildings)-43 numbers and type 3 (big buildings)-4 numbers. According to the house type, the maximum load is 1665 W, 2350 W and 4175 W for type 1, type 2 and type 3 respectively. As per the rooftop area available and usable without shading in type 1, type 2 and type 3 houses, the solar potential would be 3.9 kWp, 4.8 kWp and 7.8 kWp respectively. Thus, the total solar potential of the Star Homes would be 252.8 kWp.

The components sizing of PV system were done using the calculations in the MS-EXCEL software and simulation of energy management was done through software PV-SYST for standalone system and SAM(System Advisor Model) software for grid connected systems with battery and without battery. The necessity of battery storage is explained from the data received from outage recorded in TOD meter installed in the same feeder with maximum of 4 hours outage in a day.

According to the load profile, the size of solar system without grid dependency i.e standalone system for type 1, type 2 and type 3 house is calculated to be 1620 Wp 26V/ 322Ah, 3240 Wp 51V/302 Ah and 6480 Wp 77V/412 Ah respectively. In standalone system, PVSYST simulation results show the designed system is capable to match the load of type 1, type 2 and type 3 with annual generation of 3067 kWh, 6300 kWh and 9592 kWh respectively. Thus, the designed system is independent from the grid but the excess annual energy 795 kWh, 1744 kWh and 1429 kWh for type 1, type 2 and type 3 respectively is being wasted as unused during the condition of fully charged battery. The LCOE considering 25 years life time with 7.5 % loan interest for 15 years for type 1, type 2 and type 3 is 0.21$, 0.21$ and 0.22$ per kWh. This system aids the grid than the traditional inverter battery backup system based on grid which takes grid power to store the energy in the battery.

In the grid tied PV system without battery, the load is supplied during sunshine time by PV and excess energy is sent to the grid whereas in the off-shine time, the load takes supply from the grid. In the load profile of each houses, there is evening and morning peak which cannot be supplied through the aforesaid system, so this kind of system utilizes the grid during the peak time burdening the grid. The main short come of this nature of system is when the grid is out the whole system becomes inactive and useless during day time and night time. So, the load is not met and also the solar energy is wasted during such situation. The designed system of grid tied PV for type 1, type 2 and type 3 are 3.9 kWp, 4.8 kWp and 7.8 kWp respectively utilizing the available rooftop space. The SAM simulation results show the designed system is capable of annual generation of 6483 kWh, 7812 kWh and 12781 kWh respectively from the installed solar system. Thus, the designed system is able to export energy 5645.45 kWh, 6680.83 kWh and 11277.03 kWh for type 1, type 2 and type 3 respectively. The net savings of electricity bill after installation of the system for type 1, type 2 and type 3 house is 516$, 635$ and 1018$ respectively. The LCOE considering 25 years life period with net metering and excess energy charged at 0.073$ for type 1, type 2 and type 3 are 0.0703$, 0.073$ and 0.0689$ respectively. The NPV considering 25 years life period with net metering and excess energy charged at 0.073$ for type 1, type 2 and type 3 are 2190$, 2585$ and 4429$ respectively.

In the grid tied PV with battery system, the load is supplied from PV during sunshine time and in case of off-shine hour/power outage the battery is active and the load not met after that is fulfilled by the grid. Since there is no solar during the evening and night, such time the load can be supplied by the battery if programmed in the energy management system. From the simulation output, it is seen that the energy from the grid is very low compared to the system without battery backup system. Therefore, this system aids the grid by supplying surplus energy to the grid and sustains itself by supplying form battery during the peak time and outage period. In this regard the peak time of the grid is shifted and the load factor is also improved hence decreasing maximum demand of the grid. It is costly compared to all three system, but most reliable compared to all three system. Now days our major issue is shifting from zero load shedding to the quality, reliable supply of power. As we can see the grid is not reliable and has several outage time, the PV battery grid tied system seems to be good option supplying the load during peak time i.e. peak shaving thus lessening the burden of the grid during peak time. The designed system of grid tied PV battery system for type 1, type 2 and type 3 are 3.9 kWp with 6.6 kWh battery, 4.8 kWp with 10 kWh battery and 7.8 kWp with 10 kWh battery respectively utilizing fully the available rooftop space and available high voltage compatible battery in the market. The SAM simulation results show the designed system is capable of annual generation of 6415 kWh, 7722 kWh and 12692 kWh respectively from the installed solar system. Thus, the designed system is able to export energy 4674.35 kWh, 4371.33 kWh and 8727.67 kWh for type 1, type 2 and type 3 respectively. The net savings of electricity bill annually after installation of the system for type 1, type 2 and type 3 house is 537$, 745$ and 1158$ respectively. Moreover, the maximum peak shaving achieved for type 1, type 2 and type 3 are 0.95 kW, 1.89 kW and 1.89 kW respectively. If all houses of Star Homes install such system, the total peak shaving that would be achieved is 92.6 kW. The LCOE considering 25 years of life period with net metering and excess energy charged at 0.073$ for type 1, type 2 and type 3 are 0.13$, 0.148$/ and 0.1152$ respectively. The NPV for type 1, type 2 and type 3 are -862$, -1188$ and 628$ respectively.

Moreover, the sensitivity analysis for all types with different parameters has been presented with different outcomes. The major result show that the most profitable system is grid tied PV system without battery for residential houses supplied at grid tariff rate of block rate with net metering energy cost of 0.073$ per unit. Moreover, system with net metering and its sale rate at 0.073$ is profitable than the sale rate as of hydropower. The NPV for grid tied PV with battery system is positive when loan rate is less than 5% and also positive for type 3 design with minimal battery size as of type 2 but higher PV size. Thus, higher PV integration with lower battery size is more suitable and profitable investment for residential load. The system peak shaving using battery storage technology is not profitable at all. However, such system relieves the grid during the peak time. The peak load of Nepal is specially dominated by the residential load of lighting and cooking. Thus, with suitable policy and subsidy from the utility, the peak shaving in residential sectors would be fruitful in peak load management of INPS.

5.2 Recommendation

For the accurate daily load profile, data logger is recommended to be installed rather than determining load from the survey with questionnaires. The data from the data logger of the load shall enhance the accuracy of the designed system in fulfilling the load and optimizing the cost. The government shall see each house as a powerhouse and make suitable environment for them to install such system i.e. making the system beneficial for the installer. The Feed in Tariff, subsidy, net metering etc. shall be provided fairly to make the system sustainable. However, utilities must consider the withstand capacity for integration of distributed generation at different locations. Moreover feeders are designed with the protection settings in the protection system without considering the integration of distributed generation. Thus, the impact study for each feeder at different locations must be carried out to keep the system safely operable during integration of distributed generations. Utilities have big challenge during load management at peak time due to minimal storage and PROR hydropower plants. Thus, reliable policy intervention encouraging energy mix concept i.e increasing percentage of storage, PROR and encouraging peak shaving through use of grid interactive systems with battery backup shall be fruitful to the utility as well as the consumer. Similarly, implementation of Feed in Tariff and higher tariff at peak i.e ToD tariff with use of smart meter will further enhance use of grid interactive PV systems in the future.

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PUBLICATION

Author Name: Milana Prajapati, Bharat Raj Pahari and Shree Raj Shakya.

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ANNEXES

Annex 1

The questionnaire for the survey is as given below:

TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF MECHANICAL ENGINEERING
Questionnaire for M.Sc. Thesis Survey

General Information on Household:

District: **Municipality:** **Ward Number**:
Street: ______________ Tole:_________________
House No:_____________
House Owner's Name:____
Total Members in the family:_______________
Contact Person: Name_________________ Contact Number:___________________

Demand Profile of the household:

1. Phase of the electricity supply system at your house?
☐Phase@230V ☐3- Phase@400V ☐3-Phase@11 kV
☐Others(Specify):
2. What is the installed capacity of NEA energy supply meter in your house?
☐5A ☐15A ☐30A ☐60A
3. What is the average monthly electricity bill of your house in summer season?
☐Upto NRs. 300/Month ☐Between NRs. 300/Month to NRs. 800/Month
☐Between NRs. 800/Month to NRs. 1300/Month ☐Between NRs. 1300/Month to NRs. 1700/Month ☐Between NRs. 1700/Month to NRs. 2200/Month ☐Between NRs. 2200/Month to NRs.2700/Month ☐Above: NRs. 2700/Month
4. What is the average monthly electricity bill of your house in winter season?
☐Upto NRs. 300/Month ☐Between NRs. 300/Month to NRs. 800/Month
☐Between NRs. 800/Month to NRs. 1300/Month ☐Between NRs. 1300/Month to NRs. 1700/Month ☐Between NRs. 1700/Month to NRs. 2200/Month ☐Between NRs. 2200/Month to NRs.2700/Month ☐Above: NRs. 2700/Month
5. Please fill up the following table:

S.N.	Space Catogory	Lamp Type	No. of lamps	Watt(W)	Time duration (hr)
1	Lobby				
2	Living Area				
3	Kitchen				
4	Dining				
5	Toilet				
6	Staircase				

7	Master Bedroom				
8	Bedroom				
9	Store				
10	Terrace				
11	Puja room				

6. Please fill up the following table

S.N.	Equipment	No. of equipment	Watt(W)	Time duration(hr)
1	AC			
2	Fan			
3	Electric Stove			
4	Heater			
5	Electric Jug			
6	Rice cooker			
7	Laptop			
8	Desktop			
9	T.V			
10	Vaccum Cleaner			
11	Music Player			
12	Fridge			
13	Microwave/Oven			
14	Iron			

7. Do you have any other electrical appliances other than that mentioned in the table? If yes please mention the name of equipment, watt and time duration?

S.N.	Equipment	No. of equipment	Watt(W)	Time duration(hr)

8. Please provide the daily load consumption pattern of your house?

SN	Time Equipments	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

9. Please provide the daily emergency load consumption pattern of your house?

SN	Time Equipments	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24

10.How do you manage power supply during load shedding?

☐Using Solar PV backups ☐Using inverter battery backups
☐Using Rechargeable Emergency Lights ☐Community based Diesel Generator
☐Individual Diesel Generator ☐Using Candles ☐Bear the inconvenien
☐Others(Specify):

11. Brief descriptions of power backup systems:

Capacity/Size(KVA):____________________ Purchase Cost(NRs.):___________________
Guarantee/Warranty provided bysuppliers(Years)___________________
Expected life (Years:)__________________
Cost of Operation and Maintenance:____

12. How many hours your backup power systems covers load shedding times?

☐3 hours ☐3-5 hours ☐5-8 hours ☐8-10 hours

13. How many hours your backup power systems covers load shedding times in winter season?

☐3 hours ☐3-5 hours ☐5-8 hours ☐8-10 hours

14. For what purpose you use your backup power systems?

☐Lighting ☐Cooking ☐Entertainment ☐Computers
☐Communication/Internet ☐Photocopy/Printings ☐Water Pumping
☐Fan ☐Heater ☐Ac ☐Others(Specify):

15. How do you evaluate the performance of your existing backups systems?

☐Excellent ☐Good ☐Satisfactory ☐Poor
☐Others(Comment):

16. Are you aware of GoN Urban Solar Subsidy Policy in Nepal?

☐Yes ☐No

What is the source of the information?Specify:

17. How much are you willing to pay if 24×7 days electricity is available from Solar Energy?

☐Upto NRs. 10/Unit ☐Upto NRs. 15/Unit ☐Upto NRs. 20/Unit
☐Upto NRs. 25/Unit ☐Not willing to pay more than NEA charge
☐Can’t say right now ☐Others(Specify):____________________________

18. Considering the ever increasing load shedding in Nepal, which one of the following alternativesource of energy would you like to use?

☐Solar Electricity ☐Wind Energy ☐Community Base Solar Electricity
☐Bio-gas based Electricity ☐Community based waste to electricity
☐Others(Specify):

Rooftop Area: (*ft*x *ft* or *m x m:*)________________________

Surveyor
Name: **Milana Prajapati**
Date:_________________

Annex 2

The power consumption and energy consumption pattern for weekends is tabulated in the given table

s.n	house no.	fan(1)	fan(2)	fridge(1)	fridge(2)	induction(1)	induction(2)	t.v(1)	t.v(2)	mobile	lights	lights	lights	iron
1	4	45	60		200			150	60	40	5	40	25	1300
2	8				100			120	45	40	5	40	30	1500
3	10	50	80		270		1000		50	60	10	20		850
4	12				150		1600		45	10		50		1500
5	15		60		160		1700		60	30	10	25		1200
6	17		160		180		1500	50	60	40	10	40		
7	20	40	40		200		1200	60		40		30		1000
8	22	50	100		450		1500		80	25	10	20	10	1600
9	25		40		160		1000		60	20	10	35		
10	27		80	100	300		1800		150	40	5	30	10	
11	29		80		200		1500		70	50	5	40	10	1200
12	32		100				1700	150	50	30	10	20		1300
13	33	45	80	150	200		1300	50		30	10	20	20	2200
14	34		40		120	1000	1000	50	60	30		20		1500
15	37				130		1400	45	60	25	10	25		1200
16	42		40		150		1600	45	120	10	20	30		
17	44	40	40		100		1500	50	150	30	10	20		1500
18	49				120		1000	50	60	20	20	40		
19	50		40		120	1300	1300	50	150	40	10	50		1500
20	51	55	100	140	180		1500	45	60	60	10	50	10	1500

s.n	house no.	rice cooker	heater	desktop	washing machine	laptop	router	vacuum cleaner	e.car	e.scooter	microwave	inverter	total power	total energy
1	4	800										180	2905	10710
2	8	500										120	2500	7335
3	10				350	240	22	2000		1500	1200	120	7822	22298
4	12	750			200	150						150	4605	15695
5	15	1000			300	180	20					180	4925	17555
6	17	750			180	120	25			2000		200	5315	28360
7	20				250	100		1500				120	4580	11810
8	22				300	70	28				2000	180	6423	20042
9	25	1000		150	180	50	20				1500	200	4425	13845
10	27				230	120	30				1800		4695	16770
11	29				250	200	22	2000				200	5827	17298
12	32		1000	150	250	100	30				1400		6290	16110
13	33				500	200	25		3600		2800		11230	38350
14	34	1000			180	100	30			3000			8130	32890
15	37		1500	130	150	250	25	1600			1800	200	8550	20250
16	42				200			1700				150	4065	12465
17	44				180	150	35	1600			1600	120	7125	14350
18	49	900			150	50		1300				170	3880	11090
19	50	500			180	100	25					150	5515	16360
20	51				350	150	25	1700			2200	200	8335	23380

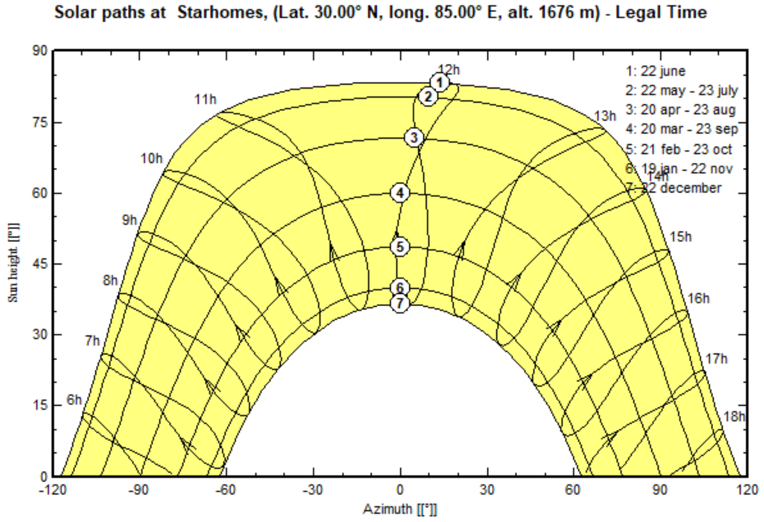
Annex 3

The power consumption and energy consumption pattern for weekdays is tabulated in the given table

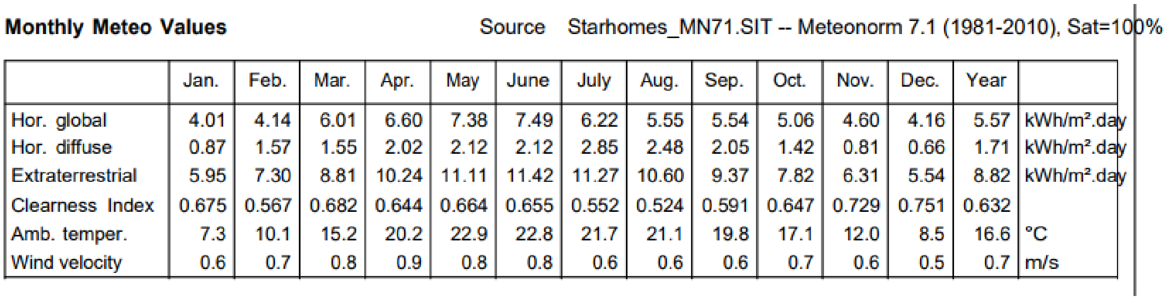
s.n.	house no.	fan(1)	fan(2)	fridge(1)	fridge(2)	indution(1)	induction(2)	t.v(1)	t.v(2)	mobile	lights	lights	lights	iron
1	4	45	60		200			150	60	40	5	40	25	
2	8				100			120	45	40	5	40	30	
3	10	50	80		270		1000		50	60	10	20		
4	12				150		1600		45	10		50		
5	15		60		160		1700		60	30	10	25		
6	17		160		180		1500	50	60	40	10	40		800
7	20		40		200		1200	60		40		30		
8	22	50	100		450		1500		80	25	10	20	10	
9	25		40		160		1000		60	20	10	35		1000
10	27		80	100	300		1800		150	40	5	30	10	
11	29		80		200		1500		70	50	5	40	10	
12	32		100				1700	150	50	30	10	20		
13	33	45	80	150	200		1300	50		30	10	20	20	
14	34		40		120	1000	1000	50	60	30		20		
15	37				130		1400	45	60	25	10	25		
16	42		40		150		1600	45	120	10	20	30		1500
17	44	40	40		100		1500	50	150	30	10	20		
18	49				120		1000	50	60	20	20	40		
19	50		40		120	1300	1300	50	150	40	10	50		
20	51	55	100	140	180		1500	45	60	60	10	50	10	

s.n.	house no.	rice cooker	heater	desktop	washing m/c	laptop	router	vacuum cleaner	e.car	e.scooter	microwave	inverter	total power	total energy
1	4	800										180	1605	9410
2	8	500										120	1000	5835
3	10					240	22			1500		120	3422	17178
4	12	750				150						150	2905	12495
5	15	1000				180	20					180	3425	12625
6	17	750				120	25			2000		200	5935	28380
7	20				250	100						120	2040	9270
8	22					70	28				2000	180	4523	17112
9	25	1000		150		50	20					200	3745	12925
10	27					120	30						2665	14500
11	29					200	22	2000				200	4377	15848
12	32		1000	150		100	30				1400		4740	14560
13	33					200	25		3600		2800		8530	35870
14	34	1000				100	30						3450	13210
15	37		1500	130		250	25				1800	200	5600	17280
16	42				200							150	3865	12265
17	44					150	35				1600	120	3845	11070
18	49	900				50						170	2430	9640
19	50	500				100	25					150	3835	14680
20	51					150	25				2200	200	4785	19480

Solar data for PV Syst simulation:



Solar path

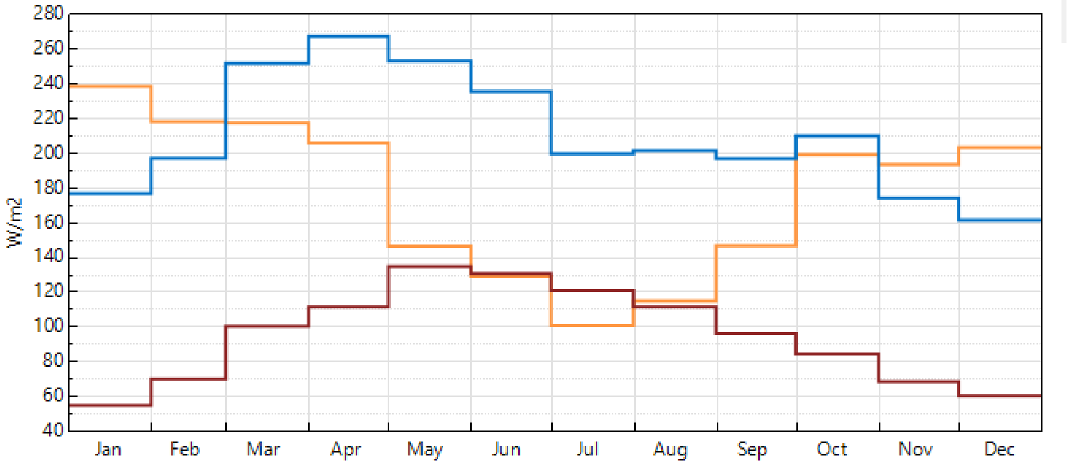


Monthly Meteo Values Source Starhomes_MN71.SIT -- Meteonorm 7.1 (1981-2010), Sat=100%

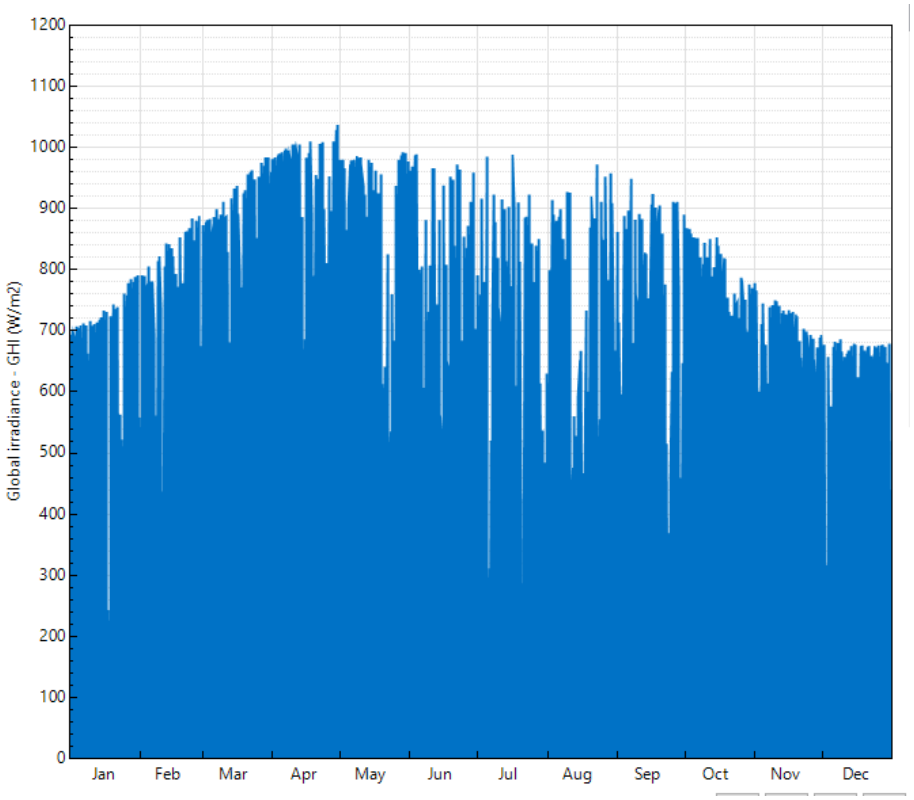
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Hor. global	4.01	4.14	6.01	6.60	7.38	7.49	6.22	5.55	5.54	5.06	4.60	4.16	5.57	kWh/m².day
Hor. diffuse	0.87	1.57	1.55	2.02	2.12	2.12	2.85	2.48	2.05	1.42	0.81	0.66	1.71	kWh/m².day
Extraterrestrial	5.95	7.30	8.81	10.24	11.11	11.42	11.27	10.60	9.37	7.82	6.31	5.54	8.82	kWh/m².day
Clearness Index	0.675	0.567	0.682	0.644	0.664	0.655	0.552	0.524	0.591	0.647	0.729	0.751	0.632	
Amb. temper.	7.3	10.1	15.2	20.2	22.9	22.8	21.7	21.1	19.8	17.1	12.0	8.5	16.6	°C
Wind velocity	0.6	0.7	0.8	0.9	0.8	0.8	0.6	0.6	0.6	0.7	0.6	0.5	0.7	m/s

Monthly Meteo values

Simulation required Meteor data for SAM:



Global irradiance , Beam irradiance, Diffuse irradiance



Global Irradiance of Months

Quantity for 7.6 kW grid tied system

Item Description	Quantity
300 Watt Mono Solar Panel	26
ACE-2P Pass-Through Box	1
100' MC4 Connector Cable	2
Disconnect Key for Solar Panel Connector Cables	1
SolarEdge 7 kW HD Wave Grid Tie Inverter V2	1
SolarEdge 320 Watt Optimizer	26
Solar Surge Protection Device 600V	2
Solar Surge Protection Device 300VDC/AC	1
Square D DU222RB 60A 240VAC Unfused Disconnect	1
Square D Ground Kit PK3GTA1	1
Burndy Multiple Wire Terminal	2
IronRidge XR100 11' Rail, Clear	16
Bonded Splice Kit for XR-100 Rails	12
End Cap for XR-100 Rails - Pair	4

IronRidge XR Universal Clamp, Black	56
IronRidge XR Stopper Sleeve, 38MM, Black	8
XR Grounding Lug w/Hardware	2
IronRidge FlashFoot 2, Mill, 4pk	11
Square Bonding Hardware, FlashFoot 2	44
Cable Clips	55
Mounting Hardware Kit for Optimizers	26
DC Conductors May Be Energized	3
Electric Shock Hazard	4
Photvoltaic Power Source	5
Turn Off PV Before Working	3
Warning Elec Shock, DC Voltage	1
Warning, Dual Power Source	1
Photovoltaic AC Disconnect	3
Main PV System Disconnect	1
Warning, Power Source Output	1
Photovoltaic DC Disconnect	1
Maximum Voltage	1
Rapid Shutdown Switch	3