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Performance Analysis of Roof-top Grid Tied Solar PV Power Plant: "A Case Study of 100kWp Solar PV Power Plant at Nepal Telecom, Chhauni"

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Performance Analysis of Roof-top Grid Tied Solar PV power plant: A Case Study of 100kWp Solar PV Power Plant at Nepal Telecom, Chhauni" submitted by Ramesh Suwal in partial fulfillment of the requirements for the degree of Master of Science in Energy System Planning and Management.

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ABSTRACT

The performance analysis for 100kWp grid-tied solar PV power plant installed at Chhauni Complex, Nepal Telecom, Kathmandu was performed. The technical and economic performance parameters were calculated from the data collected in the data logger of the inverters. The simulations of the system for installed capacity with three different scenarios were done in the PVsyst tool. The irradiance data obtained from the Department of Hydrology and Meteorology was used for simulation. The technical performance parameters for all the cases of simulations were compared. The economic analysis comparison between best scenario and actual case was done.

The technical performance parameters like Energy generation, Final yield, Reference yield, Performance ratio, capacity utilization factor, overall system efficiency for the actual case were found to be 9.75MWh/month or 325kWh/day, 3.2kWh/kW/day, 4.5kWh/m^2/day, 72%, 13.4%, 13.6% respectively. The system saves the energy bill to the owner of plant annually by NRs. 1.3 million. The economic performance parameters like NPV, IRR, LCOE and DPBP were found to be NRs.3.39 million, 17%, NRs. 7.92/kWh and 8.2 years respectively. Thus, the roof-top grid-tied solar PV power plant can be better for utility energy bill saving, own energy generation plant and use the wasted free space.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

AC	Alternating Current
AEPC	Alternative Energy Promotion Center
BS	Bikram Sambat
CES	Center for Energy Studies
CUF	Capacity Utilization Factor
DC	Direct Current
DHM	Department of Hydrology and Meteorology
DPBP	Discounted Payback Period
Eac	Energy generated to Grid
IEA	International Energy Agency
IEC	International Electro technical Commission
IOE	Institute of Engineering
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Electricity
MBS	Monthly Bill Saving
MPPT	Maximum Power Point Tracking
NDC	Nationally Determined Commission
NEA	Nepal Electricity Authority
NG	Nepal Government
NPV	Net Present Value
NT	Nepal Telecom
PR	Performance Ratio
PV	Photovoltaic
TIA	Tribhuvan International Airport
WECS	Water and Energy Commission Secretariat
YF	Final Yield
YR	Reference Yield

CHAPTER ONE: INTRODUCTION

1.1 Background

Solar Energy is the originator of all other sources of energy that exists in this earth. The most widely used energy resources in this world today that is fossil fuels are also an indirect result of trapped Sun's energy over the time(Adhikari et al.). Global warming and pollution concern due to reliance on fossil fuels for electricity generation around the world push to seeks for alternative energy sources that are environment friendly and renewable. Around 82% of global energy supply using fossil fuels for electricity generation causes 40% of global carbon dioxide emissions(Mubarak et al., 2020).Among the various forms of renewable energies like wind, biomass and others, Photovoltaic (PV) energy occupies a prominent position due to many peculiarities. The economic incentives, reduction in the PV cost and technological development in PV field makes the use of grid tied PV plants in a simple, efficient and profitable way(Tiwari et al., 2017).

In 2021 Solar PV generation is increased by 22% about 179TWh and accounted for 3.6% of global electricity generation. Solar PV remains the third largest renewable technology behind hydropower and wind (IEA, 2022). In Nepal utility scale solar PV had been in operation. About 55MW power is being generate by different utility scale solar PV power plants and many others solar PV power plants are under construction that may generate about 68MW of power and connected to grid in near future(NEA Annual Report, 2021). Some other commercial and industrial or residential scale which are installed on barren free space land or roof top of buildings are in operation. Some of them are tabulated in the table 1.1.

Photovoltaic technology is the finest way of converting the solar energy directly in the form of electricity. PV technology had been used as standalone form usually where national grid is not available or for small home system and grid connected in large scale. The installation of grid connected PV plant had been increasing very fast in last decade. The international Renewable Energy Agency (IRENA) publish the growth of solar PV technology for electricity generation as 62.43TWh in 2011 to 830.74TWh in 2020. Neighbor country China individually generate about 261.64TWh electricity from solar PV in 2020 where it'saround 2TWh in 2011. The growth of electricity generation is very high. Similarly other neighbor country India also increases its PV electricity generation from 0.305TWh in 2011 to 54.3TWh in 2020. IRENA also publish Nepal generates electricity from PV as 11GWh in 2011 and 96GWh in 2020. The growth of electricity generation from solar PV in Nepal seems very low in comparative to other countries in the world.

Table 1.1: Installed Grid tied Solar PV power Plant (Bajracharya S.M, 2019)

S. N	Location	Capacity (kW)	Remarks
1	Singhadurbar	1000	Roof-top
2	Kharipati,NEA	100	Barren Land
3	Nepal Telecom, Sundhara	65	Roof-top
4	CES, IOE, Pulchowk	1	Roof-top
5	Rara hill memorial school, Kirtipur	40	
6	ICIMOD, Khumaltar	53	Roof-top
7	NEA, Minbhavan	3.33	Roof-top

The average global radiation in Nepal varies from 3.6 to 6.2 kWh/m^2/day with average sunshine for about 300 days in a year. The average insolation intensity available in Nepal is about 4.7kWh/m^2/day. Considering 12% efficiency of PV module and average insolation of above data, the total energy generation potential of 18.36 TW of power can be generated. (Adhikari K. et al.)

Nepal Government conducts a policy for the increment of electricity generation from solar PV under which Nepal Government aimed to connect the solar PV technology in national grid with the upper limit of 10% of total connected capacity of generation as energy mix concept of energy development technologies. Under this concept, Nepal Electricity Authority, a NG owned organization of Nepal called proposal for bid the solar PV installation and generates electricity and fed directly to the national grid. NG also float a procedure for the easiness of installation of solar PV from private developer, institution and individual house owner. Many grid-connected solar PV had been installed in Nepal. Some of them are utility scale and some are institutional. Among the institutional solar PV power plant, Nepal Telecom, a government owned company install solar PV power plant on roof top of its building at various location of Nepal. One among the such power plant is located in the Chhauni complex. NT had installed 100kWp of solar PV power plant on the roof of store shed and the roof of the office building. The roof of the store shed is little slanted and the roof of the office building is flat. This thesis studies the details of that solar PV power plant and analyzed the performance parameters defined under the IEC standard 61724 for performance of solar PV since its installation. The performance of solar power plant installed on flat roof and slanted roof is also under the study of this thesis and the comparison will be done the different in the performance.

1.2 Problem Statement

To meet the low emission energy production there is global trend in adoption of renewable energy source and Nepal is also following this trend. There is numerous Solar PV plant being installed for selling energy as well as consuming energy. Due to ease and fast installation comparative to the Hydropower and autonomy for energy independency, Solar Power Plant is becoming more attractive. Many developers, institution and individuals are installing it, but those power plant may not be actually producing energy as designed and expected. The installation of solar PV system is done as free space available. Performance of many grid-connected solar power plant is not as designed due to many practical problems during operation, assessment of performance of this grid connected solar plant is one path of efficient power production.

Nepal Telecom Chhauni had also installed grid tied solar on the roof top of its office building and roof of store shed. The PV modules are installed as free space available in the complex. NT had used the free space available over there. Approx. 600 sq. meter of shed slanted roof and 325sq. meter of building roof are available in the site and the solar PV plant installed leaving some space in the roof. The Plant seems to be installed as peak power of 100kWp to be installed since some free space is still available over there. Some PV modules are installed on flat roof with tilt angle of 30° and azimuth 0° and some PV modules are installed on slanted roof, tilted at both edge of solar panel facing south direction. Usually, the PV modules are installed parallel to roof if it need to installed at slanted roof. But in this site the PV modules are installed facing south direction with tilt parallel to roof as well. Thus, the normal to the plane of the solar panel is not actually facing south instead some angle with the south and the performance of the solar power plant installed at flat roof of the building and slanted roof of the store shed may not be similar in the similar environment. The performance of the solar PV power plant installed at different orientation must have different performance. Thus, the different in performance for the PV power plant installed in different orientation need to be studied for better output and recommendation for next such projects.

1.3 Objective

Main Objective

To conduct Performance analysis of the 100kWp Solar PV Plant installed at Nepal Telecom, Power Department, Chhauni.

Specific Objectives

i. To determine performance parameters and economic parameters of overall installed system.
ii. To determine the energy generation and technical performance parameters forInstalled capacity of solar PV plant considering all PV modules installed at tilt angle 30° and azimuth 0°, PV modules on slanted roof at roof orientation and PV modules installed as in siteby simulation on PVsyst tool.
iii. To compare the technical performance parameters of simulated cases and actual case.
iv. To compareeconomic parameters for best case with existing case.

1.4 Assumptions and Limitations

i. Shading loss, Soiling loss and Grid Fault loss are not considered in the simulation.
ii. The data collected are for one year in Bikram Sambat 2078.
iii. The irradiance data used for the simulation is the data collected in the Tribhuvan International Airport (TIA) station by Department of Hydrology and Meteorology (DHM).
iv. The equivalent tilt angle and the azimuth angle are used during the simulation of actual scenario.

CHAPTER TWO: LITERATURE REVIEW

2.1 Energy Scenario of Nepal

Nepal Energy Sector Synopsis Report 2022 by Water and Energy Commission Secretariat (WECS) shows that 66% of total energy consumption in 2021 is fulfilled by traditional energy sources like fuel woods, Agriculture residues etc. The energy consumption pattern by fuel type is shown in Figure 2.1. Only 4.2% of electricity and 2.4% of renewable energy sources are used in the corresponding year. The total installed capacity of electricity Generation by hydropower, thermal and solar is 2190MW (NEA annual report, 2022). About 961 thousand of off grid solar home system were installed mostly in hilly regions. As per solar and wind energy resources assessment (SWERA) by Alternative Energy Promotion Center(AEPC), the commercial potential on grid-connected Solar PV plant is about 2100MW (NESSR, 2022).

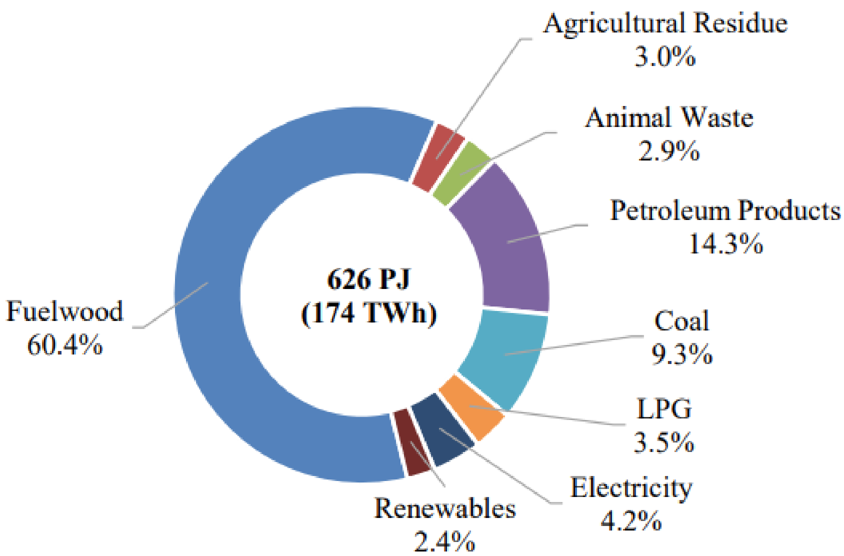

Figure 2.1: Energy Consumption by fuels type in 2021(NESSR, 2022)

Similarly, the sectoral energy consumption in the year 2021 is shown in Figure 2.2. The highest energy consumption is in residential sector which is followed by industrial, transport and commercial sector. The electricity consumption on these sectors can be fulfilled by solar energy, off-grid and on-grid solar PV power plant. Around 4000MW of electricity generation is targeted to achieve from renewable energy resources by 2030 as per the National Planning Commission's 15th periodic plan. With a goal of producing more than 550MW by 2024, the government also wants to boost the proportion of solar energy generation through private sectors. Additionally, as part of the NDC target, Nepal intends to add 2100MW of solar energy to the national grid by 2030, meeting 15% of the nation's total energy consumption with renewable energy sources. (GoN, 2020).

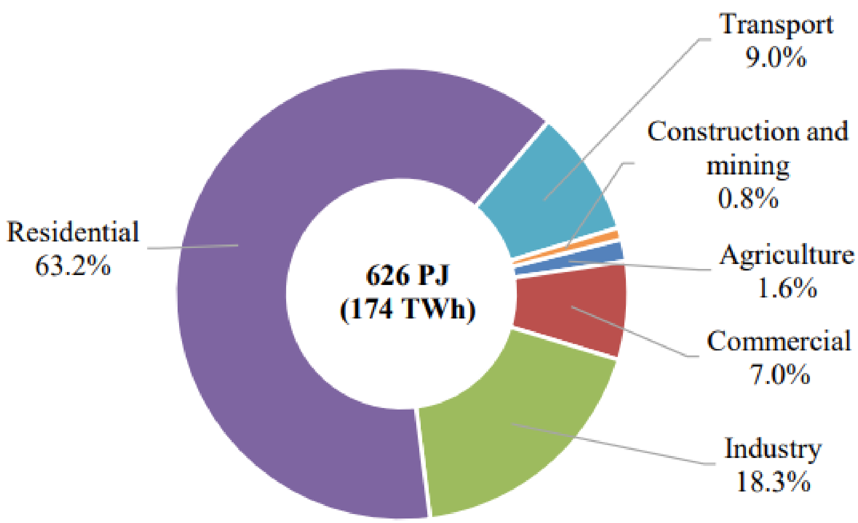

Figure 2.2: Energy Consumption by Sectors in 2021(WECS,2022)

2.2 Grid-tied Solar PV power Plant

The grid-tied solar PV power plant is different from the standalone PV plant by storage of power. The grid-tied solar PV power plant is connected to national grid such that the power generated by the plant is fed to the grid. Thus, battery backup system is not available in this system. Since the plant is connected in series to the grid, there is extra protection from shock hazards. Special inverter other than off-grid or hybrid systems shall be used in this system. The on-grid inverter is provided with anti-islanding mechanism which does not allow power to flow back to grid from the system while the grid is in off state. This mechanism provides the protection to the work personnels working on grid for maintenance. The grid-tied solar PV power plant schematic diagram is shown in Figure 2.3.

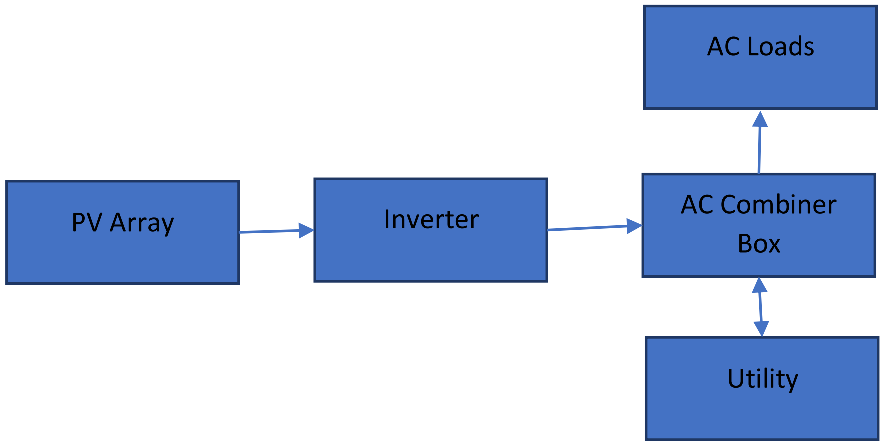

Figure 2.3: Grid-tied Solar PV power plant schematic diagram

2.2.1 Components of Grid-tied solar PV power plant

The main components of the grid-tied solar PV power plant are:

2.2.1.1 Solar PV modules

The photovoltaic effect, which occurs silently and without the use of any moving parts, allows the PV modules to convert solar radiation directly into electricity. The photovoltaic effect is a semiconductor action in which sunlight striking semiconductor photovoltaic cells causes electron movement. A solar PV cell produces direct current (DC) as its output. (Shakya A.M.,2015).

2.2.1.2 Inverters

The various photovoltaic (PV) systems use inverters as power electronic equipment. The selection of an appropriate inverter is the first step in designing a grid-connected solar system. In turn, the solar generator can be tuned in accordance with the input characteristics of the solar inverter once the system voltage on the DC side has been established. The inverter is the second most crucial part of a photovoltaic system that is connected to the grid (after the solar generator). Its job is to change the direct current produced by the solar cells into a grid-compliant 50-Hz alternating current.

2.2.1.3 Transformers

The output from the inverters requires a further step- up in voltage to reach the AC grid voltage level. The step-up transformer takes the output from the inverters to the required grid voltage. (Shakya A.M.,2015).

2.2.1.4 The grid connection interface

The electricity is exported here and into the grid system. The PV power plant will be protected and isolated by the necessary grid interface switchgear, including circuit breakers and disconnects, as well as generation and supply metering equipment, in the substation. The metering point and substation are frequently outside the PV power plant perimeter. Typically, they are situated on the network operator's grounds. (Shakya A.M.,2015).

2.2.1.5 Net meter and Check meter

Residential and commercial customers that produce their own electricity from solar power can input electricity into the grid thanks to net metering.Owners of solar energy systems receive credit for the electricity they supply to the grid through a billing system called net metering. Most solar customers generate more electricity during the day than they need; net metering enables them to export that energy to the grid and lower their future electricity costs. (Shakya A.M.,2015).

2.3 Previous study on Grid tied Solar PV power plant

Many national and international study had been done on the Grid-tied Solar PV power plant. Some of the research that had been done are discussed here.

Bhattarai (2004) conducted a study on a grid-connected PV system in Nepal and discovered that urban homes, where power might be produced by solar photovoltaic technology in individual homes and could be connected to the national grid, are the main consumers of the grid. His research also shown the financial viability of grid-connected solar systems with subsidies.

In a case study on grid-integrated solar power for the National Dasarath Stadium, Shakya (2015) found that the levelized cost of electricity (LCOE) for a utility-scale hybrid grid-tied solar power plant would be NRs.18/kWh for 20 years while the LCOE for a fully grid-tied plant would be NRs.23/kWh. The cost of a 20-year solar PV facility would be NRs.12.5/kWh. This study found that by exploiting the advantages of a grid-tied solar PV plant, Nepal's lone national stadium could eliminate the need for diesel generators, reduce daytime utility electricity costs, and operate sustainably.

Ayompe et al. (2011) conducted research on the measured performance of a grid-connected 1.72 kW rooftop photovoltaic system in Ireland and discovered that the system's final yield and reference yield were 2.41 kWh/kW/day and 2.85 kWh/kW/day, respectively. This analysis also found that the system's performance ratio and capacity utilization factors were, respectively, 0.815 and 10.1%.

For an 80kWp grid-connected roof top Transformer-less photovoltaic power plant in Tamilnadu, India, Kumar and Nagarajan (2016) analyzed the performance ratio and the various power losses (power electronic, temperature, soiling, internal, grid availability, and connections). According to this study, the system's performance ratio was 0.838 and its capacity utilization rate was 18.26%.

In his study Techno-Economic Analysis of Utility Size PV Project, A Case Study on a 1 MWp Plant at Trishuli, Shrestha (2014) discovered that the plant's system yield and capacity utilization factor would be 4.81 kWh/kWp/day, 20.18%, and 0.773, respectively. He also calculated that the cost of the plant's power would be NRs. 10.5/kWh. His final finding was that utility-scale grid-tied solar PV plants are technically and financially viable for addressing Nepal's energy need.

In Khatkar-Kalan, India, Sharma and Chandel (2013) carried out a performance analysis on a 190 kWp grid-connected solar photovoltaic power plant. The outcome gave insight into the solar power plant's long-term performance under its actual operational circumstances in India. The system under study had a system efficiency of 8.3%, a capacity factor of 9.27%, and a performance ratio of 0.74.

A study done by Padmavathi K. et al., in 2013 shows that a 3MW capacity of the Solar PV plant installed in India had 60% of performance ratio and final yield of 3.73 kWh/kWp/day. It is mentioned by the author that the PR and final yield is lower for the period due to high inverter failure and it was reduced later on thus PR was improved to 0.7 and inverter failure losses was reduced from 818MWh to 409MWh.

In northern Brazil, Lima et al. (2017) conducted a study on the performance analysis of a grid-connected photovoltaic system and discovered that the system's reference and final yields were, respectively, 5.6 kWh/kW/day and 4.6 kWh/kW/day. The research also revealed the system's performance ratio and capacity utilization factor were, respectively, 0.829 and 19.2%.

A study done by Yadavalli S. et al. in 2019 shows that a 33kWp installed capacity of the solar PV plant in India had performance ratio of 0.743 which is better than in comparison to the other plant installed in another site of India. The author found the final yield is about 4.05kWh/kWp/day. The author recommend that the efficiency of module used play role in the overall output of the Plant. The efficiency of the module used in the plant was 15.38% which is better than the module installed in another site. However, the author recommended to use more efficient PV modules.

Another study done in Nepal by Ghimire K. et al. for the capacity of 8MW which is utility scaled grid tied PV plant installed at Butwal Nepal found maximum PR of 0.79 on January and lowest on May with 0.66 PR. The annual average PR for the system was found 0.72 which is quite good comparative to the other studies done in India. The capacity utilization factor for the system was found highest in march with 19.95% and lowest in January with 11.87%. The author had also calculated the LCOE for the system and found NRs. 6.7/kWh which is lower than the tariff rate offered by the government of Nepal. This shows the solar PV plant is quite better for utility scale.

A study done in Northern India by Yadav and Bajpai in 2018 for the solar PV plant system of installed capacity 5kWp had found the annual average daily reference yield as 5.23kWh/kWp/day, array yield of 4.51kWh/kWp/day and final yield of 3.99kWh/kWp/day. The PR for the system was found 0.7697 and Capacity utilization factor 16.39% that are quite good than other studies in India.

Effect of Small Decentralized PV Grid Linked Plants on Load Shedding in Nepal was studied by Chianese (2014) et al. They discovered that the energy output was as high as anticipated and comparable to the irradiation level. The irradiation level was 22% lower than NASA meteorological data for the seven-month analysis period. A small distributed grid-connected system with a capacity of up to 50 MW may be quickly erected in the Kathmandu valley, according to the research, and would contribute to the improvement of the nation's access to electricity.

In order to increase energy generation from a constrained metropolitan region, Rachchh et al. (2016) conducted a study on solar photovoltaic system design optimization using shading analysis. This study indicated that 25% additional land area might be used efficiently for the installation of solar PV systems by optimizing tilt angle and taking the shadow into consideration. When compared to the increase in installed capacity by more than 25%, this could result in a loss of less than 1% in terms of specific generation (kWh/kW).

The performance of an 11.2 kWp grid-connected rooftop PV system in Eastern India, which was observed from September 2014 to August 2015, was presented by Sharma and Goel (2017). According to this study, the system's performance ratio was 0.78, and the total amount of energy produced throughout the study period was 14.96 MWh.

In order to maximize power under partial shading conditions, Pendem and Mikkili (2018) conducted a study on modeling, simulation, and performance analysis of solar PV array configurations (series, series-parallel, and honey-comb). This study discovered that when the number of PV modules per string and the number of shaded strings in a PV array rises, mismatched power losses lower the maximum power generation capacity.

2.4 Technical Performance parameters of Solar PV power plant

The continued growth of the photovoltaic (PV) sector depends on accurate and reliable assessments of solar photovoltaic (PV) system performance. Performance assessments serve as a gauge of an existing product's quality for component makers. They are a crucial metric for research and development teams in determining future demands. These are essential tools for assessing products and product quality for systems integrators and end users to inform future decision-making.

The IEC standard 61724:1998 describes the performance characteristics that have been created by the International Energy Agency Photovoltaic Power Systems (IEA

PVPS) Program in order to analyze the performance of Solar PV systems. By comparing their normalized system performance statistics, such as yields, losses, and efficiencies, photovoltaic systems with various configurations and in various locations can be easily compared (IEC, 1998). Yields are energy amounts that have been assessed array power-normalized. System effectiveness is scaled to array size. Losses are the variations in yields. Due to load matching and other distinct operational features, the performance parameters of grid-connected, standalone and hybrid PV systems might change dramatically. These performance parameters include (Sharma and Chandel, 2013: Marion et. Al. 2005):

i. Total energy generated by the PV system (EAC)
ii. Final yield (YF)
iii. Reference yield (YR)
iv. Performance ratio (PR)
v. Capacity utilization factor (CUF)
vi. Overall system efficiency (η_{system})

2.4.1 Total energy generated by the PV system (Eac)

The total daily and monthly energy generated by the PV system is given by the equation 1 and equation 2 respectively.

$$E(AC,d) = \sum_{t=1}^{24} E(AC,t)$$

$$E(AC,m) = \sum_{d=1}^{N} E(AC,d)$$

Where N is the number of days in the month. E(AC,d) is the Energy generated in the day, E(AC,m) is energy generated in the month, E(AC, t) is the instantaneous energy generation.

2.4.2 Final Yield

The total AC energy generated by the PV system for a defined period (day, month or year) divided by the rated output power of the installed PV system is Final Yield(Y_f). It is given by

$$Yf = \frac{Eac}{Ppv, rated}$$

2.4.3 Reference Yield

The ratio of total in plane solar insolation H_t (kWh/m^2) to the reference irradiance G (1 kW/ m^2) is the reference yield (Y_r). The parameter represents equal number of hours at the reference irradiance and is given by

$$Yr = \frac{Ht(\frac{kwh}{m2})}{G(\frac{kW}{m2})}$$

It is a function of the location, orientation of the PV array, and month-to-month and year-to-year weather variability.

2.4.4 Performance ratio

the ratio of the final yield (YF) to the reference yield (YR) is Performance ratio (PR). This dimensionless quantity normalizes performance with respect to incident solar radiation and offers crucial details on the overall impact of losses when converting DC to AC. The system performs better than other systems in comparable environmental conditions the greater the PR of the system. A PR of 0.8 and higher, according to the EU Performance study, indicates a system that performs well (Khalid et al., 2016). A number of nations, including the US, Australia, and the European Union, have created PV monitoring regimes that use PR as one of their primary performance indicators. Several PV plant operators' experiences suggest that continual PR monitoring aids in the correction of system flaws. PR readings typically vary from 0.6 to 0.8 and are higher in the winter than the summer. If PV module soiling changes with the seasons, it might likewise affect the PR's summer to winter variations. A permanent performance decline may be indicated by declining yearly values (Marion et al., 2005).

$$PR = \frac{Yr}{Yf}$$

The performance ratio shows the entire impact of losses on the array's rated output caused by array temperature, inadequate irradiation use, and system component inefficiencies or malfunctions (IEC, 1998). It is a quantity without units. This metric is used to assess long-term performance changes, and declining year-by-year PR values are a sign of performance decline. It shows the percentage of energy that is actually available after accounting for energy losses (Okello et al., 2015).

2.4.5 Capacity Utilization Factor

The capacity utilization factor (CUF) is defined as the ratio of the actual annual energy output of the PV system to the amount of energy the PV system would generate if it operates at full rated power (PV, rated) for 24 h per day for year and is given as:

$$CUF = \frac{Eac,a}{Ppv,rated * 8760}$$

2.4.6 Overall System Efficiency

A PV system's efficiency is broken down into three categories: inverter efficiency, system efficiency, and PV array efficiency. These efficiencies can be calculated on an instantaneous, hourly, daily, monthly, and annual basis, depending on the data at hand and the desired level of detail. The ratio of the system's total AC energy output to the total energy gathered from the PV field is known as the overall system efficiency. (Carmo de Lima et al., 2015).

$$\eta system = \frac{Eac}{Ht * Apv,array} * 100$$

where, Eac = total energy output by the system (kWh),

Ht = total in-plane solar insolation (kWh/m^2),

Apv,array = total area of the PV system

2.5 Economic Performance parameters

The electricity tariff and the sources of revenue affect the solar PV system's return on investment. Based on the economic factors that define the economic performance of PV systems, different investment analyses are conducted. The energy bill saving for the period can be considered as revenue for the economic parameter calculation. In the section below, the economic parameters that are taken into account while evaluating a PV system are discussed.

2.5.1 Net Present Value (NPV)

Net present value (NPV) is the difference between the current worth of cash inflows and withdrawals over a period of time. In capital budgeting and investment planning, NPV is used to assess the profitability of a planned investment or project. Calculations are done to arrive at the NPV, or present value of a stream of future payments, using the proper discount rate. Positive NPV projects are typically worthwhile to pursue, but negative NPV projects are not. The discount rate may take into account the cost of capital or the benefits provided by alternative investments with comparable risk. A project's or investment's positive net present value (NPV) predicts a higher rate of return than the discount rate. (Fernando J., 2022).

Analyzing a longer-term project with multiple cash flows, then the formula for the NPV of the project is as follows:

$$NPV = \sum_{t=0}^{n} \frac{Rt}{(1+i)^t}$$

Where, Rt is the net cash inflows-cash outflows during the period t,

i is the discount rate or the rate of return that can be earned in alternative investment.

t is time period.

NPV can be calculated in Excel as well using the formula:

=NPV(discount rate, future cash flow) + initial investment.

2.5.2 Internal Rate of return (IRR)

The internal rate of return (IRR) is the anticipated yearly rate of growth from an investment. IRR calculates it by setting net present value (NPV) to zero, just like NPV. The ultimate goal of IRR is to calculate the rate of discount that reduces the investment's initial net cash outlay to the present value of all of its initial nominal yearly cash inflows. The greatest tool for analyzing capital budgeting projects in order to evaluate and compare likely yearly rates of return across time is the internal rate of return (IRR). IRR can help investors determine the investment return of different assets and is also used by businesses to decide which capital projects to fund. (Fernando J., 2023).

The formula and calculation used to determine this figure are as follows:

$$0 = NPV = \sum_{t=1}^{T} \frac{Ct}{(1 + IRR)^t} - C0$$

Where, Ct is the Net cash inflow during the period t,

C0 is the total investment costs

IRR is the internal rate of return

t is the number of time periods.

IRR can be calculated in Excel by using the function IRR.

2.5.3 Levelized cost of electricity (LCOE)

The levelized cost of electricity (LCOE) represents the average net present cost of producing electricity for a generator over the length of its lifetime. It is frequently used to compare various electricity generation methods and for investment planning. The LCOE is calculated as the ratio of all the discounted costs over the course of a power plant's lifetime divided by the discounted sum of the actual energy amounts delivered, and it "represents the average revenue per unit of electricity generated that would be required to recover the costs of building and operating a generating plant during an assumed financial life and duty cycle." (Lai C. et. Al., 2017)

The costs incurred throughout the period of the plant's planned lifetime and the anticipated amount of energy it will produce are what define the cost of producing energy. The levelized cost of electricity (LCOE) is the average cost per energy unit.

The total of all production costs is added together, and the predicted energy output is divided by this sum to determine the LCOE.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{It+Mt}{(1+r)^t}}{\sum_{t=1}^{n} \frac{Et}{(1+r)^t}}$$

Where, I_t is the investment expenditures in the year t

M_t is operation and Maintenance expenditure in the year t

E_t is electrical energy generated in the year t

r is discount rate

n is expected lifetime of the system

2.5.4 Monthly Bill Saving

The monthly bill saving is the saving of the energy consumption from utility due to the energy generation from the Solar PV plant. The energy generation during high tariff rate gives high monthly saving. However, the high tariff rate is not beneficial to the consumer, the monthly Bill saving will be higher for high tariff rate as only bill waive out is tariff charges.

2.5.5 Payback period

The payback period is the length of time needed for an investor to break even or to recover the cost of their investment. Shorter payback periods make investments more appealing, while longer payback periods are undesirable. To find the payback period, divide the investment amount by the annual cash flow. Account and fund managers take the payback period into account when determining whether to move further with an investment. One of the downsides of the payback period is that it ignores the time worth of money. (Kagan J., 2023). The Payback period is calculated as:

Payback Period = Cost of Investment/ Average Annual Cash Flow

The discounted payback period is used in capital planning because it takes time worth of money into account. The discounted payback period is more precise than the conventional payback period calculation since it takes time value of money into consideration. The projected cash flows of the project are compared to their current value to determine the discounted payback period calculation, which determines how long it will take to repay an investment. The discounted payback period must be as short as possible given that the sooner a project or investment generates cash flows to cover the initial cost, the better. (Kenton W., 2020).

2.6 Simulation Software

A computer simulation program called PV_{SYST} is used to study, categorize, and evaluate complete solar photovoltaic systems. This program can handle stand-alone, solar lift and grid connected solar photovoltaic systems. With just a few system variables, the PVSYST program can calculate monthly PV system yields, load profiles, and predicted system costs. Within the framework, the user can run several simulation iterations and contrast the outcomes with current values. The PV_{Syst} tool lets users to build more extensive system parameters and investigate light impacts such as mismatch and incidence angle losses, thermal behaviors, module quality, partial shadings of surrounding objects on the array and wiring cable loss. Many simulation variables are provided by the findings, which can be exported to other software and shown in hourly, daily, or monthly values (Thotakura et al., 2020).

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Framework

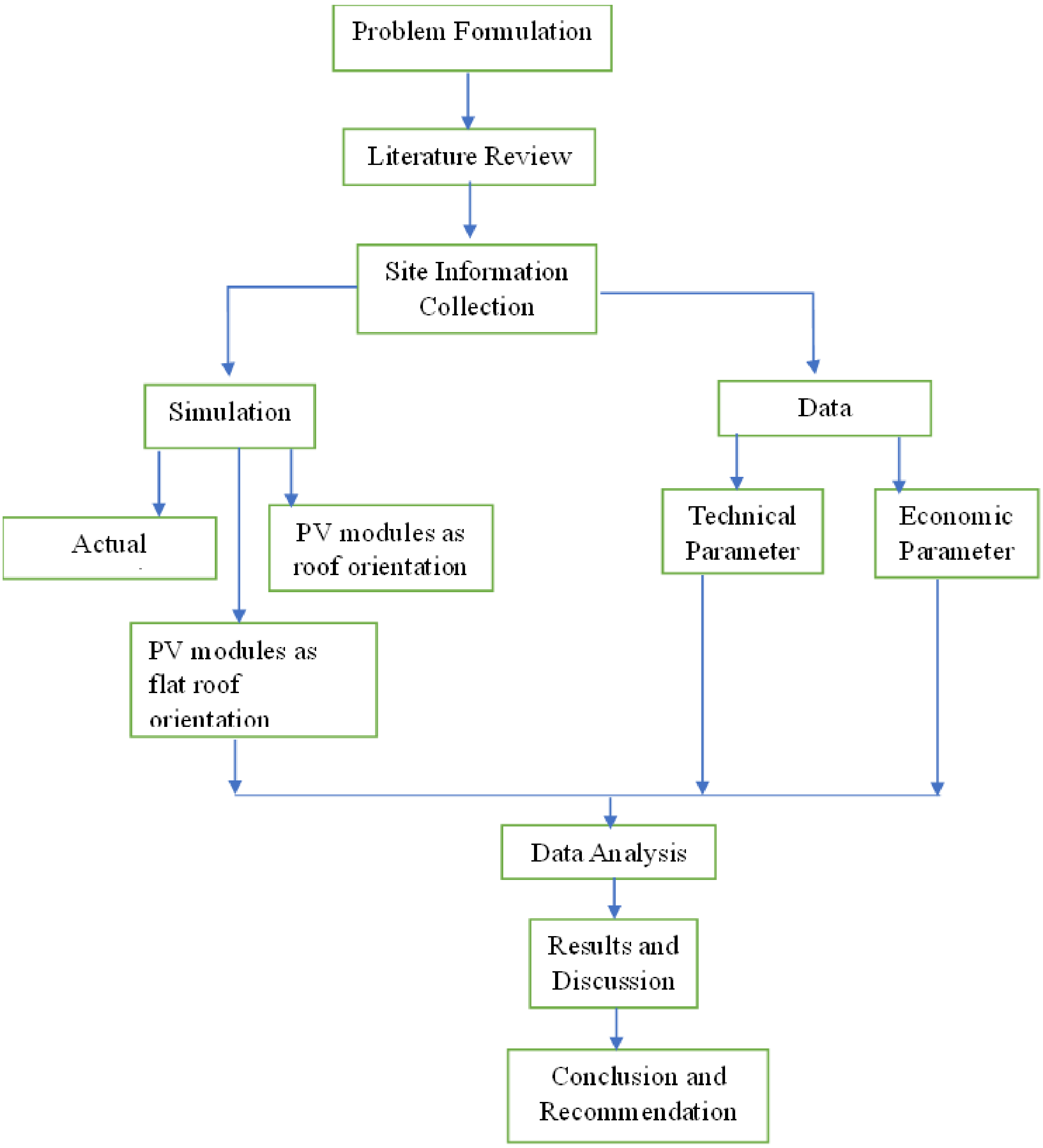

Figure 3.1: Framework of Research

The basic methodology followed in this research is as shown in the framework in Figure 3.1. After Problem identification and basic literature review, the data collection was done on site visit and technical data were collected from the data logger of the inverter installed in the site. The irradiance data is collected from the department of hydrology and meteorology. The simulation for the same capacity as installed in the site was done in the PVsyst software. The simulation was done for three different cases. The site data collected are analyzed for performance parameters calculation and economic parameters calculation.

3.2 Data Collection

The details site information, the energy generation data and the irradiance data were collected with the help of google earth, site visit and from the other official that keep records on the irradiance.

3.2.1 Site information

The site under the study is located at Chhauni, Museum Road, Kathmandu, Nepal. The Solar PV plant is installed on the roof of office building and the roof of the store shed. The roof of the building is flat horizontal surface and the roof the shed is slanted at 25^o facing east-west both directions. Some of the photographs related to the Solar PV plant installed at the site are shown in the Figure 3.2 and Figure 3.3. The PV plant was installed and commissioned on Feb 2021.

Figure 3.2: PV modules on flat roof

The PV modules installed on flat roof are tilted thirty-degree and oriented zero-degree azimuth. The PV modules installed on slanted roof are tilted both edges. One edge is tilted as roof inclination and other edge tilted thirty-degree to the horizontal plane. Thus, the normal to the PV module plane is not exactly facing south neither east or west exactly. In this way the PV modules orientation are in three orientation and approximately divided in equal numbers. Since the modules are half cut, there is rare case for shading on the modules. However, the rear part of the modules on west side of slanted roof have little shading due to tree aside it as clearly seen in the Figure 3.2 and figure 3.3.

Figure 3.3: PV modules on Slanted roof

3.2.2 Solar Modules

The PV modules are main component of the plant. Two hundred and sixty-seven SRP-375-BMA modules of each capacity 375W are connected in series and parallel combination for overall capacity of 100.125kWp PV plant. The exact specification of the PV module is as shown in the sticker on back of panel in figure 7.

Table 3.1:Technical parameters of PV module (Seraphim Solar System Co., Ltd)

Technical Parameters	Specification
Module Type	Mono Crystalline
Peak Power at STC Pmp	375Wp
No. of PV cells	72 cells
Max. Voltage Vmp	40.05 V
Open Circuit Voltage Voc	48.1 V
Max. Current Imp	9.26 A
Short Circuit Current Isc	9.70 A
Module Efficiency	19%
Dimension	1.996*0.992*0.04 m
Pm Temp. coefficient	-0.38%/ °C
Voc temp Coefficient	-0.28%/°C
Isc temp Coefficient	+0.05%/°C

The technical parameters of the PV module are shown in the table 3.1.

The 18 nos. of PV modules are connected in series in a string forming 14 nos. of string and one string had 15 nos. of PV modules, forming all together 15 string of PV modules. The installation of the modules is at three different orientations. The flat roof had PV modules tilted at thirty-degree facing south. Similarly, same tilt and same orientation at south facing roof. The slanted roof of the store shed had little different orientation and tilt. The slanted roof of the store shed had east faced and west facing roof. The PV modules are mounted with tilt angle of thirty degree facing south and tilted east as roof slope on east faced roof and similar to west faced roof.

3.2.3 Inverter

Two number of grid-tied inverters named Sunny Tri power STP 50-40 core 1 are installed. The specification of the inverter is shown in figure 8. The seven string of PV modules are connected in one inverter and eight string of PV modules are connected in another inverter. Each inverter has input power capability of 75kWp at STC whereas the rated output power of the inverter is 50kW. The general technical parameters are summarized in the table 3.2.

Table 3.2:General Technical specification of inverter (SMA solar Technology)

Technical Parameters	Specification
Rated Output power	50 kW
Max. input voltage	1000 V
Rated input voltage	670V
Vmp voltage range	500 V – 800 V
Min input voltage	150 V
Max. operating input current/per MPPT	120A / 20A
Max. Short Circuit current per MPPT	30A
No. of MPPT inputs/strings per MPP input	44714
Efficiency	98%

3.2.4 Energy Generation

The energy generation data are collected from the data logger of the Inverters. The daily basis power output with 15min interval is saved in the logger. The energy generated by the Solar PV power plant is connected to Mains panel through the inverter. The energy generated are used within the complex and minimize the utility supply decreasing the utility bills. The study periods were taken for the year 2078 BS (April 2021 to March 2022). The energy generated by the Plant during the study period is shown in table 3.3. The maximum generation is in the month March and the minimum generation is in the month August. The daily generation data collected from the site from data logger of the inverter is shown in the Appendix B.

Table 3.3:Energy Generation by plant

Month	Energy Generation	Average	Max	Min
April	10538.91	9751.9	544.399	84.312
May	9428.323	9751.9	539.058	55.38
June	9527.075	9751.9	538.429	41.567
July	8676.451	9751.9	460.858	80.46
August	8459.201	9751.9	471.784	112.615
September	9521.268	9751.9	531.481	103.695
October	10993.95	9751.9	481.008	96.919
November	8915.414	9751.9	387.122	96.409
December	8615.019	9751.9	368.085	28.178
January	8806.991	9751.9	398.182	70.661
February	10697.21	9751.9	479.686	30.27
March	12842.44	9751.9	499.463	242.294
Total for a year	117022.2	9751.9	544.399	28.178

The monthly average energy generation for the year is 9752kWh. As a seasonal distribution, the spring season seems higher generation since this season is most sunny period in the year. The maximum generation in a day was 544.34kWh in the month April and the minimum generation in a day was 28.18kWh in the month December. However, the maximum energy generation was in the month March with total energy of 12.8MWh and minimum energy generation was in the August with the total energy of 8.46MWh. The total monthly generation was found above the average in the month April, October, February and March while rest of the months have its total generation below the average generation. However, the month May, June and

September have slightly low than the average generation clearly shown in the Figure 3.4. showing the variation of energy generation over the study period.

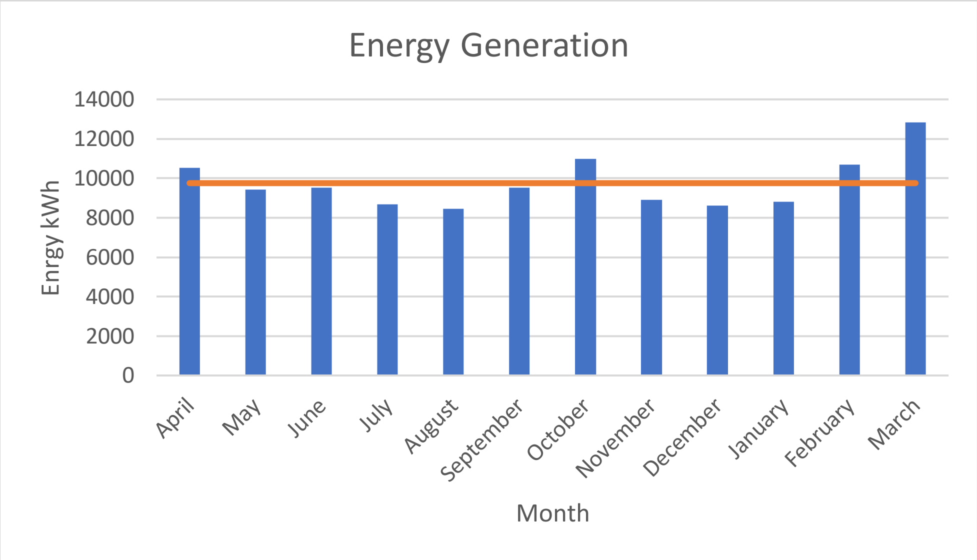

Figure 3.4: Energy Generation variation in a year

3.2.5 Irradiance data

The irradiance data is collected from the Department of Hydrology and Meteorology (DHM), Data section. The irradiance data for the study site is collected from the nearest irradiance measurement site by the DHM. The nearest station was the Tribhuvan international Airport (TIA), Kathmandu. The data collected from the DHM was irradiance with one hour average in a day. The sample data provided from the DHM for a month of April 2021 was shown in the Appendix A. The data obtained are uploaded to PVsyst tool for the Simulation purpose.

3.3 Simulation

The simulation of the existing capacity of solar PV power plant was done in PVsyst software. The simulation was done for the three cases. The first case of simulation was considering all the PV modules installed in tilt angle $30^0$and azimuth 0^0 that is same for both flat roof and slanted roof.The second case of simulation considering PV modules installed on slanted roof as roof orientation that is Some modules on flat roof with tilt 30^0 and azimuth 0^0 and some modules at tilt 25^0 and azimuth -90^0 and some modules at tilt 25^0 and azimuth $+90^0$. The third case of the simulation was considering as PV modules installed as installation done at the site. The equivalent tilt angle and the azimuth for the orientations in the slanted roofs are used for this case. Each case is described below.

3.3.1 Simulation for all PV modules installed as in flat roof (Case I)

For this case of Simulation, all PV modules are assumed to install in 30^{o} tilt and 0^{o} azimuth. The simulation was done in PVsyst software. The irradiance data was imported to PVsyst meteo file that is obtained from the DHM. The PV modules and inverters are assigned as actual scenario found in the database of PVsyst. For this case, if the PV modules shall be installed in the field some more investment shall be done in the structure. The energy generation for the case is tabulated in table 3.4. The highest energy generation for the case was is in the month March and the lowest energy generation for the case was in the month July. This shows the generation is higher in the Spring season and lower in summer season. The yearly generation is about 157.7 MWh.

Table 3.4:Energy Generation for case I

Month	E_Grid, kWh
Apr. 21	14629
May. 21	10816
Jun. 21	10446
Jul. 21	10362
Aug. 21	10854
Sep. 21	12237
Oct. 21	15117
Nov. 21	15334
Dec. 21	14048
Jan. 22	12883
Feb. 22	14881
Mar. 22	16042
Year	157649

3.3.2 Simulation for PV modules as roof orientation (Case II)

In this case of simulation, several orientations were used. Some PV modules were used as 30 ^{o} tilt and 0 ^{o} azimuth which can be installed in the flat roof as in actual scenario. Some PV modules were used as 25^{o} tilt and -90 ^{o} azimuth and some PV modules were used as 25^{o} tilt and +90 ^{o} azimuth as of available roof orientations. Similar to previous cases, the irradiance data were imported to PVsyst from the data obtained from DHM. The PV modules and Inverter were used as in PVsyst database that is similar to the real filed PV modules and the inverter. The energy generation data is tabulated in the table 3.5. For this case, if the PV modules shall be installed in the real field, the investment made on structure can be slightly lower than that done in actual scenario. The energy generation is highest in the month March and lowest in the month July showing the similarity to the previous cases. The annual generation is about 151.5 MWh.

Table 3.5: Energy generation for case II

Month	E_Grid, kWh
Apr. 21	14911
May. 21	11657
Jun. 21	11459
Jul. 21	11195
Aug. 21	11411
Sep. 21	12159
Oct. 21	13890
Nov. 21	13186
Dec. 21	11780
Jan. 22	11209
Feb. 22	13339
Mar. 22	15233
Year	151428

3.3.3 Simulation as PV modules in the site (Case III)

For this case of simulation, PV modules tilt and orientations were given as in the real field site. Some of the PV modules that were on flat roof in actual scenario are given tilt 30^{o} and orientation 0 ^{o}, some modules were given 35 ^{o} tilt and orientation -42 ^{o} and some PV modules were given 35 ^{o} tilt and orientation +42 ^{o}. The tilt and orientation are taken equivalent tilt angle of tilt of edges of PV modules. similar to the case I and case II, the irradiance data were imported from the file obtained from DHM. The energy generation data for this case is tabulated in the table 3.6. The energy generation for this case is higher in the month March and lower in the month July. The highest and lowest generation for the case is similar to the last cases but the higher energy generation is slightly lower than that of first case and the lower energy generation is slightly higher than the first case. However, the annual energy generation is lower than that of first case. The annual energy generation is about 151.4 MWh which is slightly higher than the case II.

Table 3.6: Energy Generation data for case III

	E_Grid, kWh
Apr. 21	14151
May. 21	10568
Jun. 21	10230
Jul. 21	10095
Aug. 21	10538
Sep. 21	11817
Oct. 21	14439
Nov. 21	14541
Dec. 21	13278
Jan. 22	12226
Feb. 22	14215
Mar. 22	15405
Year	151504

3.4 Project Investment

The total capital investment for the installation of the solar PV power plant was about 70 lakhs including all necessary materials. About 47% of the total investment is for PV modules which life is assumed to be 25 years. The investment cost for the inverters is about 10 lakh which is16% of total investment and solar Frame is about 9% of total investment. The investment for the solar frame structure is minimal comparative to others equipment. However, the investment in the solar frame may vary Net present value (NPV) and the Levelized cost of the energy (LCOE). In the study, the three cases may have different in investment cause of the investment in the solar frame structure since different design of the structure may need for different cases. The investment information is shown in table 3.7 and the investment breakdown can be clearly seen the pie-chart figure 3.5.

The investment for case I need little more investment than existing one, Case II need little less investment than existing and Case III is as in the existing state. The extra investment necessity for the Case I may vary as per design. However, the investment necessity for Case I is assumed to 20%extra of the existing frame, that is only 1.8% of the total investment.

Table 3.7: Investment information (Energy Audit Report, 2078)

S. N	Description	Cost
1	PV modules	3,200,000.00
2	Frame	650,000.00
3	Junction boxes	5,000.00
4	Installation materials, cable and Accessories	107,000.00
5	Inverter	1,130,000.00
6	Installation Cost	200,000.00
7	Transformer	515,000.00
8	other cables	1,069,628.62
	Gross total	6,876,628.62
	VAT	192,010.00
	Net total	7,068,638.62

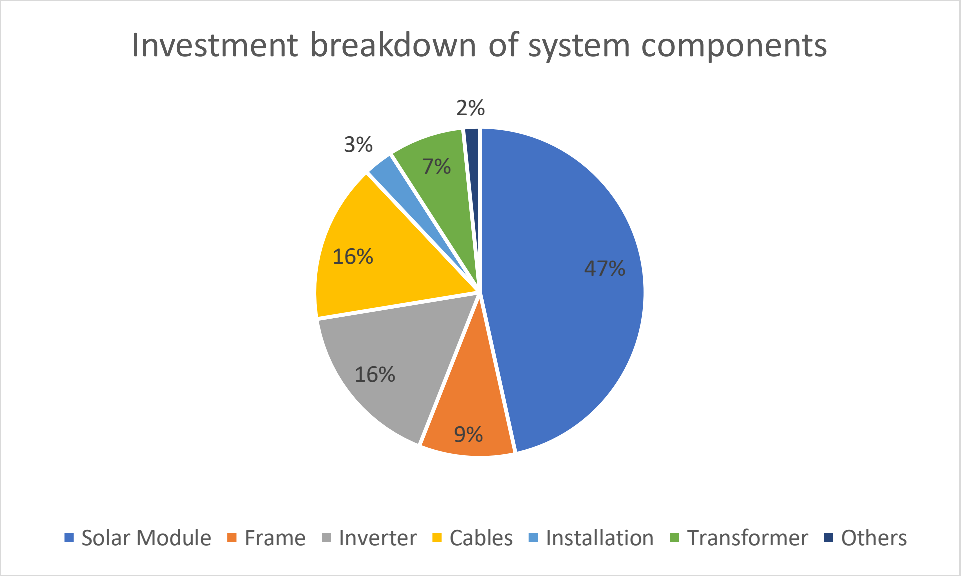

Figure 3.5: Investment Breakdown of system Components

3.5 Energy Tarriff

The Solar PV power plant is installed without net metering. Since the load of the complex is higher than the Power plant, there is zero possibility to feed the power to grid and all the generation is consumed within the complex. Thus, the Power plant is used to minimize the energy consumption from the utility company and hence minimizing the energy expenses. The screenshot of the source of the tariff is shown in Appendix F.

The consumer is 11kV middle voltage supply type commercial Consumer. As shown, the tariff rate is different for dry and wet seasons and time of day as well. The consumer is the Time of Day paying consumer. The energy tariff for the consumer is around NRs 11.10 per unit (NEA Annual Report, 2022) of energy consumption throughout the year during the normal time or day time. The energy tariff of energy consumption during peak time is NRs 12.60(NEA Annual Report, 2022). Thus, energy generation by Solar PV plant after 5pm would have more Monetary value saving to consumer.

3.6 Energy Bill Saving

The solar PV power plant in the site generated to the energy which is consumed by internal load. Thus, the energy consumption from the utility is minimized that minimize the utility bill. The saving is more with the higher tariff. Since the consumer is Time of Day consumer with middle voltage (11kV) customer, the tariff rate for the customer is NRs. 11.10. thus, saving that amount per unit of energy generation. The energy generation after 5pm has saving of NRs 12.60 per unit of energy generation. The energy consumptionfrom the utility in the consecutive year before and after installation of the Solar PV power plant is collected from the NT office. The energy consumption for the year 2077 and the year 2078 are shown in table 3.8.

The energy consumption seems more in winter season comparative to another season. It may be use of the electrical heater for heating. The comparative energy consumption from the utility is lower in the following year after the installation of the Solar PV power plant. However, the energy consumption may be increasing due to load increment in the following year. The comparative energy consumption from the utility for the consecutive two-year 2077BS and 2078BS is shown in the figure 3.6.

Table 3.8: Energy Consumption in the site in two years (NT office)

	Year	
Month	2077	2078
Baisakh	36107.00	35236.00
Jesth	42618.00	34714.00
Asadh	49162.00	40857.00
Shrawan	49408.00	47431.00
Bhadra	46313.00	42551.00
Asoj	47315.00	41510.00
Kartik	42435.00	37089.00
Mangsir	43992.00	41309.00
Poush	49059.00	44210.00
Magh	53802.00	43280.00
Falgun	32042.00	39754.00
Chaitra	34477.00	35233.00

The solar PV power plant is in operation since Falgun 2077BS. Thus, the energy consumption drastically decreases since that month and the energy consumption is comparatively low in other months in the year 2078BS. The energy consumption in Falgun of 2078BS is higher than in 2077BS as the load usually increases in successive year due to addition of new services operation and addition of new equipment. However, the solar PV power plant reduced the energy consumption from the utility.

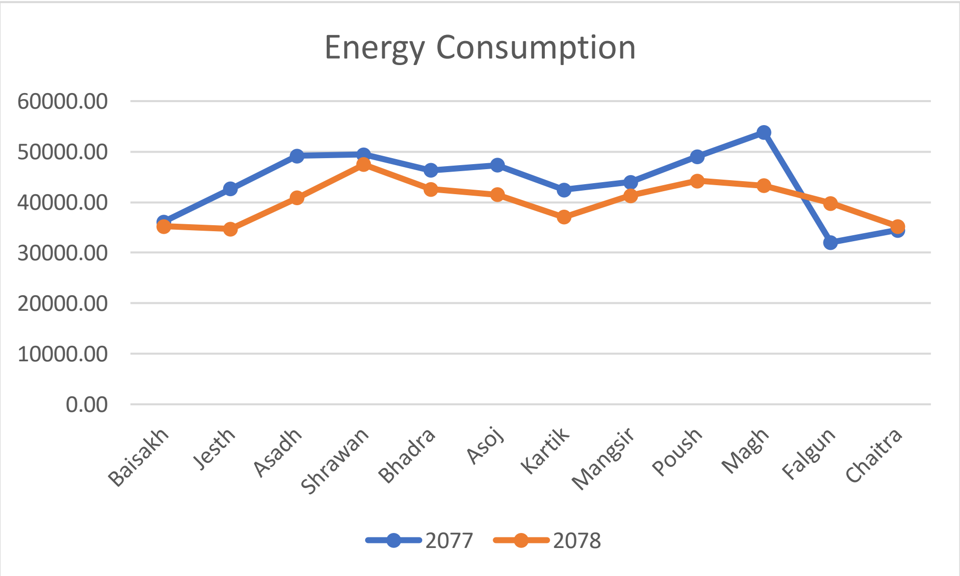

Figure 3.6: Energy consumption comparison

CHPATER FOUR: RESULTS AND DISCUSSION

4.1 Performance Analysis of 100kWp Solar PV plant

Following technical parameters were calculated and discussed for the 100kWp Solar PV plant installed at Chhauni complex of Nepal Telecom. Since the plant was in operation since 2077 Magh month, the analysis was done for the year 2078 BS.

4.1.1 Maximum Power Generation

The maximum power generation in kW by the plant is shown in the figure 13.

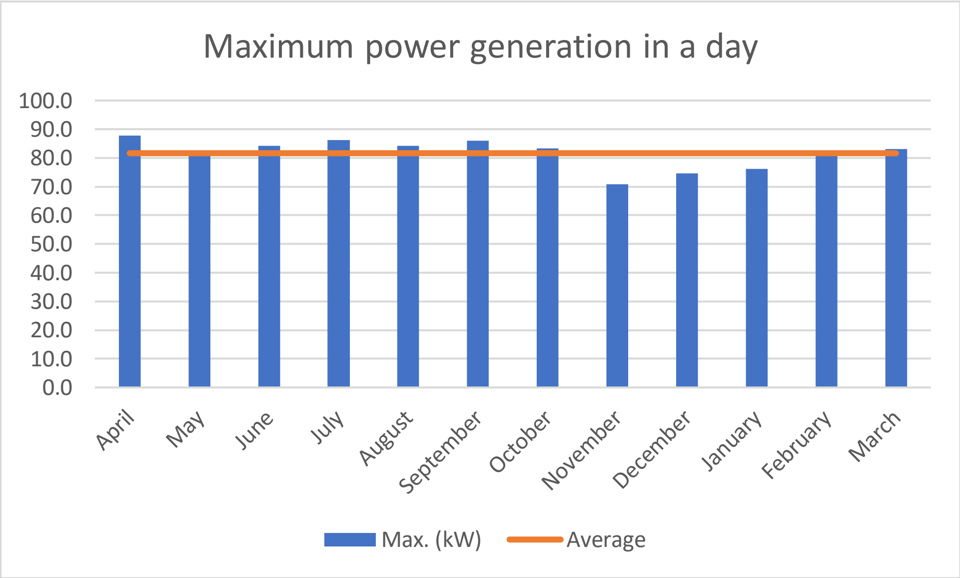

Figure 4.1: Maximum power Generation in a day

From the figure 13, the maximum generation in a day is 87.8kW in the month of April and the minimum is in the month November. The figure 13 shows the maximum power generation in a day is above the average in the summer season and below average in the winter season.

4.1.2 Energy Generation

The monthly generation for the period of a year for three different cases of simulation and the actual is shown in the figure 14. The actual monthly generation is in the month of March and minimum in the month of August in that year. The yellow curve in the figure is actual monthly generation. The maximum energy generation is 12.84

MWh and minimum energy generation is 8.46MWh and the average actual monthly energy generation is 9.8MWh.

Similarly, the simulation done as site condition shows the monthly generation for the month March, 15.23MWh is maximum and the generation for the month July, 11.20MWh is minimum. The average monthly generation for this case is 12.6MWh. The other two cases of simulation results show that the monthly energy generation is lower than case II during summer season and higher than case II in winter season. However, the Case III has similar energy generation pattern with case I. The total annual generation for the case I is highest than others and the annual generation for the other cases is nearly same and the generation is higher for case III than case II. However, the annual generation for the case III is little bit higher than the case II.

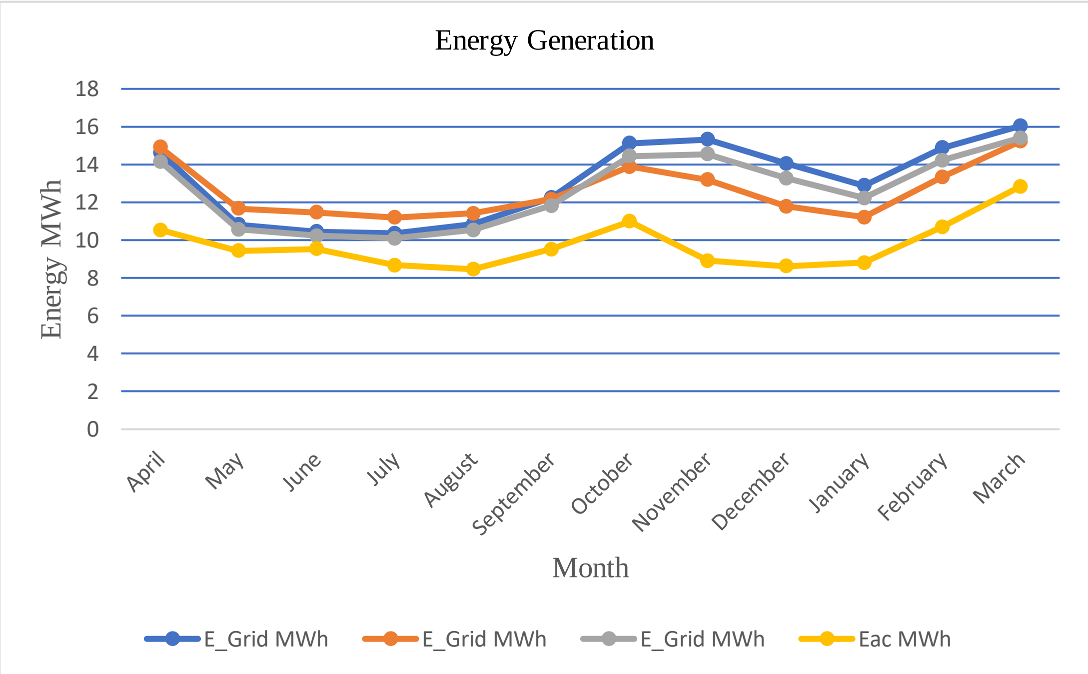

Figure 4.2: Monthly Energy Generation comparison

The energy generation difference in case I and Case III is shown in table 10. The energy generation difference in the month November is about 790kWh which is highest in the year and lowest difference is in the month June with 220kWh. The annual generation difference is about 6120kWh. The difference in the annual energy generation between case I and case III seem nearly half month generation of actual maximum generation month. The monetary value of this energy generation difference may have different in economic parameters.

Table 4.1: Energy Generation Difference in Case I and Case III

	E_Grid Case I	E_Grid Case III	Difference
	MWh	MWh	MWh
Apr. 21	14.63	14.15	0.48
May 21	10.82	10.57	0.25
June 21	10.45	10.23	0.22
July 21	10.36	10.1	0.26
Aug. 21	10.85	10.54	0.31
Sep. 21	12.24	11.82	0.42
Oct. 21	15.12	14.44	0.68
Nov. 21	15.33	14.54	0.79
Dec. 21	14.05	13.28	0.77
Jan. 22	12.88	12.23	0.65
Feb. 22	14.88	14.22	0.66
Mar. 22	16.04	15.41	0.63
Year	157.65	151.53	6.12

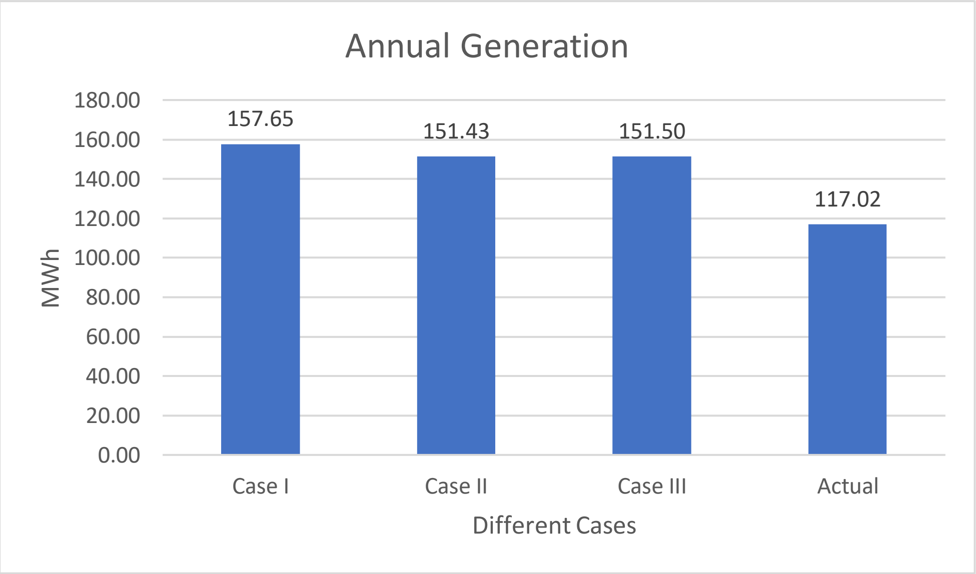

Figure 4.3: Total Annual Generation for three simulated cases and actual

The annual generation for case I is 157.65MWh, for case II is 151.43MWh, case III is 151.5MWh and the actual annual energy generation is 117.02MWh. The annual generation seems higher in the case I but nearly equal for case II and Case III. The actual generation is much lower than simulated may be due to shading and soiling losses which is not consider in simulation.

4.1.3 Final Yield

The final yield for all three case is find out and compared with each other and with actual final yield. The comparative final yield for simulated three cases and actual is shown in figure 16. The actual final yield varied from 2.73kWh/kWp/day in the month August to 4.14kWh/kWp/day in the month March whereas the simulated actual yield varied from 3.34kWh/kWp/day in the month July to 4.55kWh/kWp/day in the month March. Similarly, the final yield for other two simulated cases had maximum in the month February and minimum in the month July.

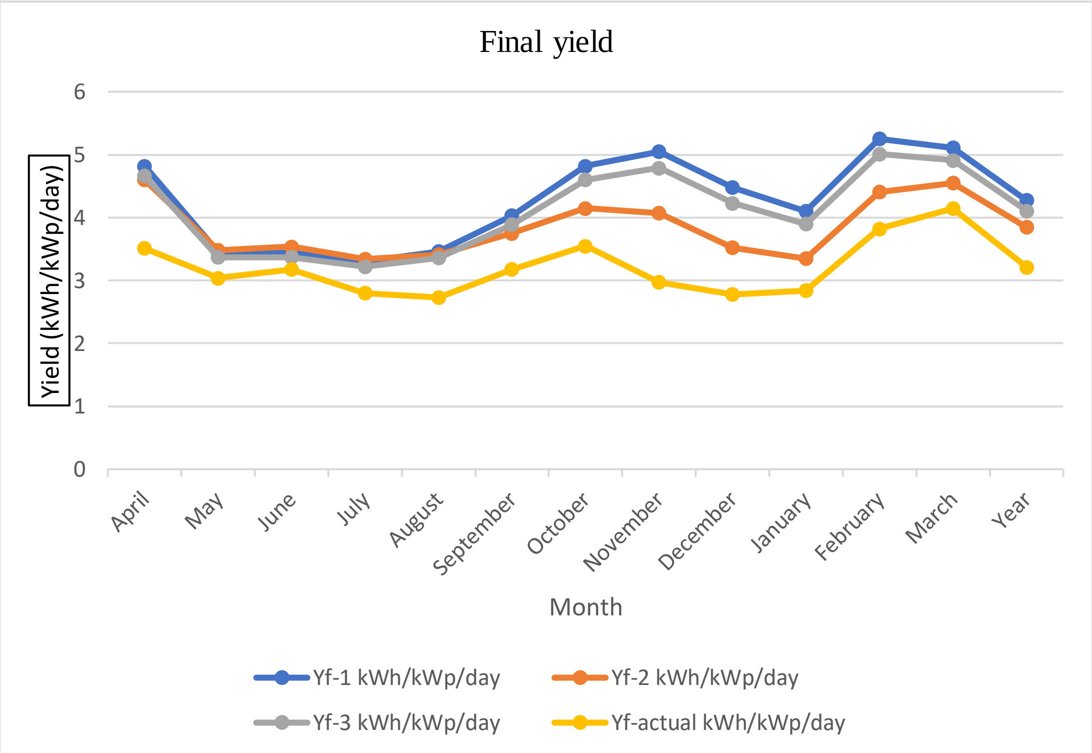

Figure 4.4: Final Yield

The final yield yearly averaged are 4.276kWh/kWp/day, 3.848kWh/kwp/day, 4.109kWh/kWp/day and 3.211kWh/kWp/day for simulated case I, case II, case III and actual respectively. The yearly final yield is higher for simulated case I and lower for simulated case II. The simulated case III which might have lower investment had higher final yield than that of simulated case II, which is similar to actually placed in the site. This study had not done shading loss which may affect the output in these cases. The higher investment in the case II may lower the shading loss comparative to case III in this particular site. However, for the site where the surrounding infrastructure is absence, case II with lower investment can be better.

4.1.4 Reference Yield

The reference yield for all three case is find out and compared with each other and with actual reference yield. The comparative reference yield for simulated three cases and actual is shown in figure 17. The actual reference yield varied from 3.36 kWh/m^2/day in the month January to 5.82kWh/m^2/day in the month April whereas the simulated reference yield varied from 3.74kWh/m^2/day in the month January to 5.47kWh/m^2/day in the month March. Similarly, the reference yield for other two simulated cases had maximum in the month March and minimum in the month June.

The reference yield yearly averaged are 5.06kWh/m^2/day, 4.58kWh/m^2/day, 4.89Wh/m^2/day and 4.51kWh/m^2/day for simulated case I, case II, case III and actual respectively. The yearly reference yield is higher for case I and lower for case II in the simulation.

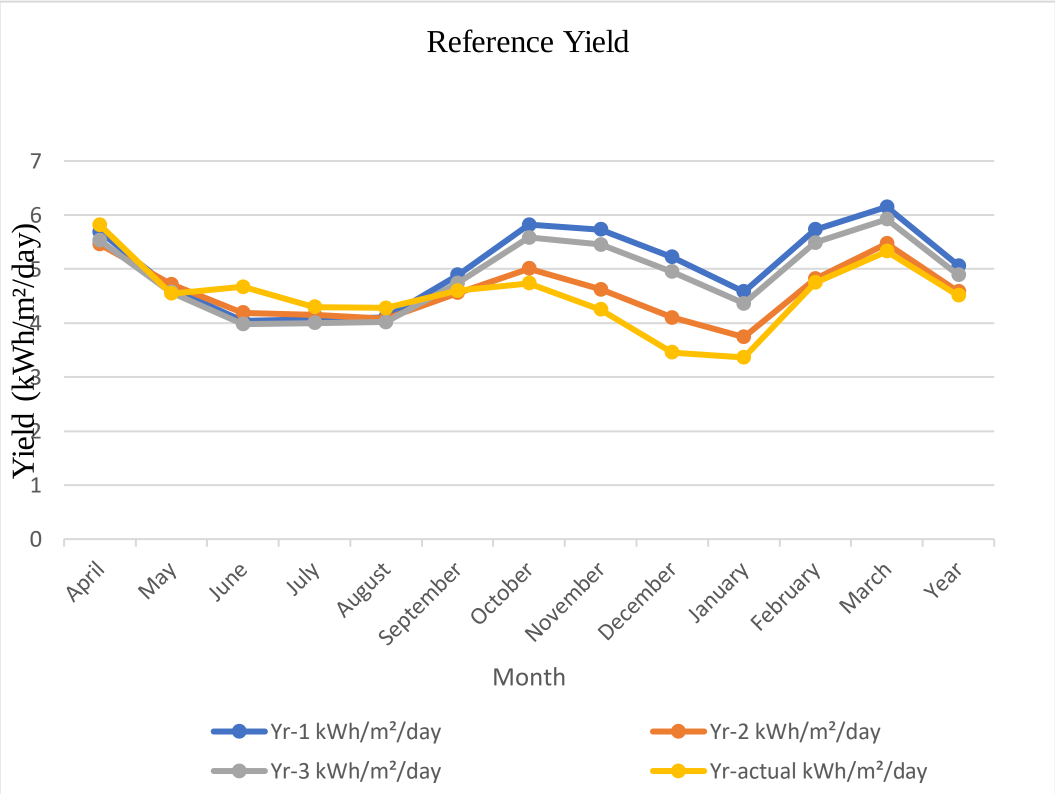

Figure 4.5: Reference Yield

4.1.5 Performance Ratio

The performance ratio comparative chart is shown in figure 19. The performance ratio is found higher in winter season and lower in summer. The actual PR varies from 0.64 in the month August to 0.84 in the month January with the yearly averaged PR of 0.72. The simulated PR varies from 0.816 in the month May to 0.896 in the month January with the yearly averaged PR 0.893. The simulated PR for all three cases nearly similar. However, the PR is higher for the simulation case I.

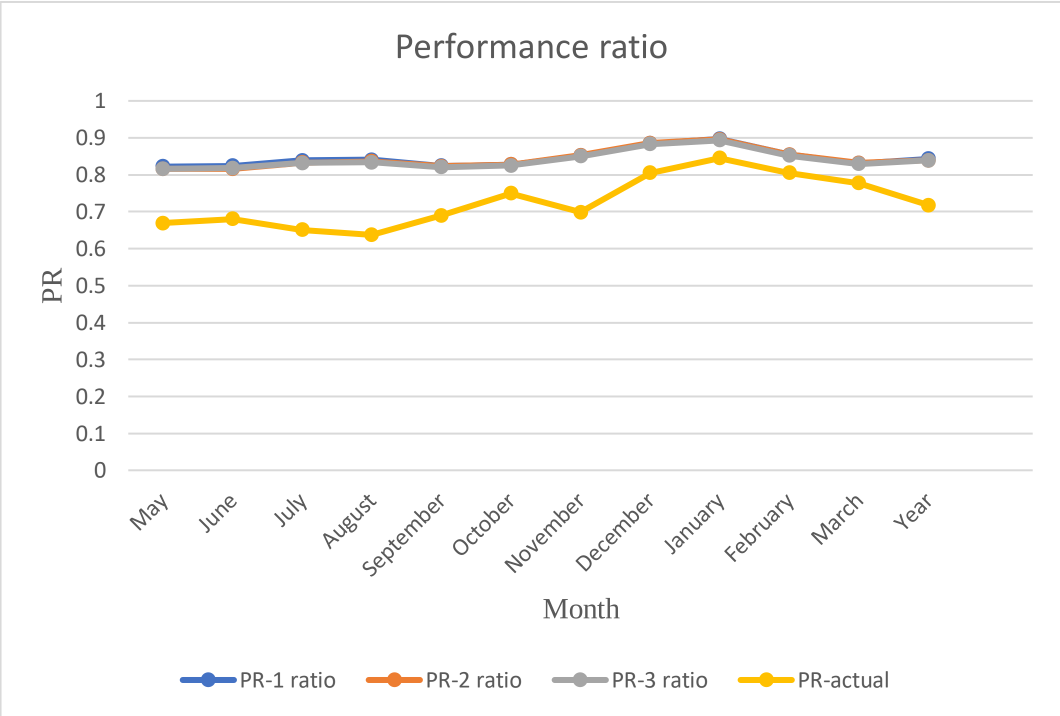

Figure 4.6: Performance Ratio

4.1.6 Capacity Utilization Factor

The figure 4.7 shows the comparative graph for Capacity utilization factor CUF of the Plant. The actual CUF is minimum in the month August with 11.4% and maximum CUF in the month March with 17.3%. Similarly, the simulated CUF varies from 13.9% in the month July to 19% in the month March. The CUF is higher in winter and lower in the summer season. The cloudy and rainy environment in the wet season affects the CUF. The clean sky at dry season enhance the use of the plant more for the energy generation resulting high CUF and high energy generation in the March.

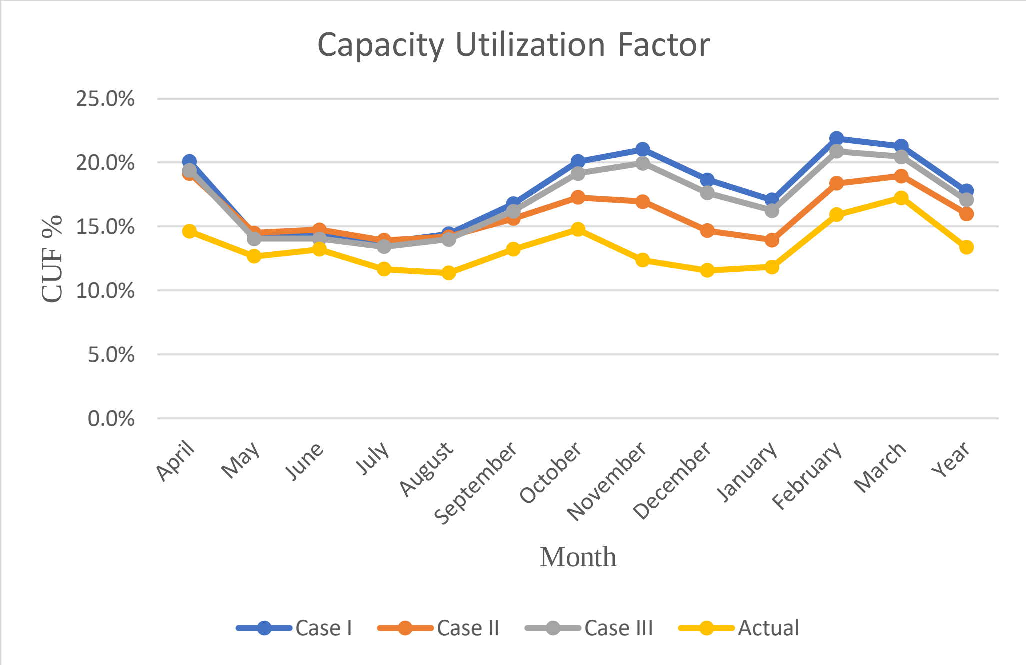

Figure 4.7:Capacity Utilization Factor

The yearly averaged CUF for actual and simulated were found 13.4% and 16% respectively. The CUF is also higher for the case I followed by case III ad case II in the case of simulation.

4.1.7 System efficiency

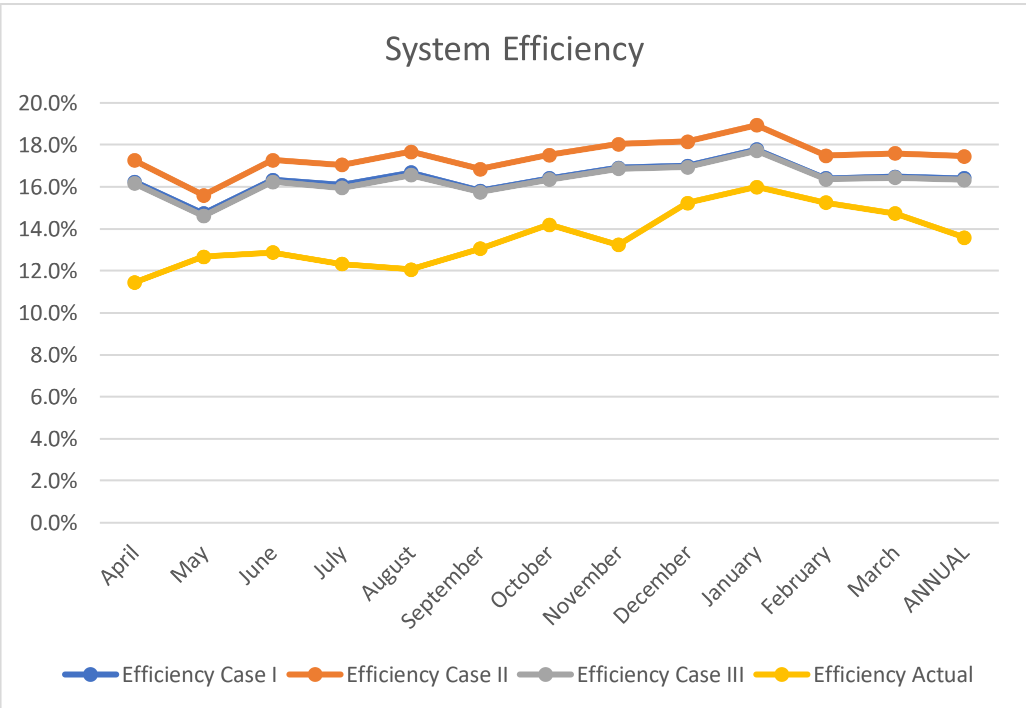

Figure 4.8: System Efficiency

The overall system efficiency of the PV plant is shown in figure 4.8. The efficiency for the case I and case III are almost similar throughout the year and for case II is little bit higher than other cases and actual efficiency. The energy generation in the case II is during morning time and evening time. This is during lower temperature. Thus, the energy generation comparative to reference is higher resulting higher efficiency.

The actual system efficiency is highest in the month January equal to 16% and minimum in the month April equal to 11.44%. This shows the efficiency is higher at winter season that is during lower ambient temperature. This can be seen in the higher efficiency in case II, which energy generation is at lower ambient temperature comparative to others.

4.2 Economic Parameters Analysis

The Economic performance parameters are calculated in the Excel Worksheet. The calculation is done assuming the life of the Plant as 25 years, discount rate as 10%, Energy tariff rate as NRs. 11.10/kWh. The economic performance parameters like NPV and IRR are directly calculated using the formula provided in the excel.

4.2.1 Net Present Value

The NPV value of the PV Plant is positive for discount rate up to 16.5%. Figure 18 shows the graph of variation of the NPV over the discount rate.

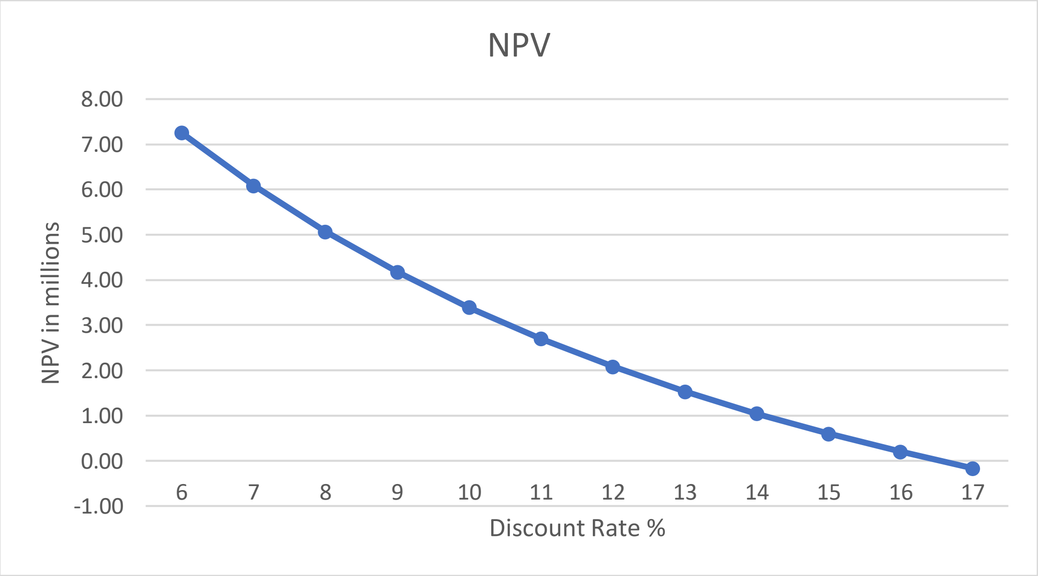

Figure 4.9: Net Present Value for the plant.

The NPV of the plant for discount rate 10% is NRs 3.39 million. Similarly, the NPV for discount rate of 8%,12% and 17% are NRs. 5.06 million, NRs 2.08 million and NRs -0.16 million. Since, the NPV is negative for 17% of discount rate, financially it won't be viable above 16.5% discount rate. Since the NPV is positive, the Solar PV system is economically good.

4.2.2 Internal Rate of Return

The variation of IRR for the plant over the tariff rate is shown in figure 19. The IRR is nearly 5% for tariff NRs. 6/kWh and below. The IRR at the tariff NRs. 11.10/kWh which is the company paying to utility for energy consumption is 16.5%. The IRR for the plant is just about 8.6% if the energy generation is paid by utility company at NRs. 7.3/kWh. The IRR for the plant is higher for higher tariff rate.

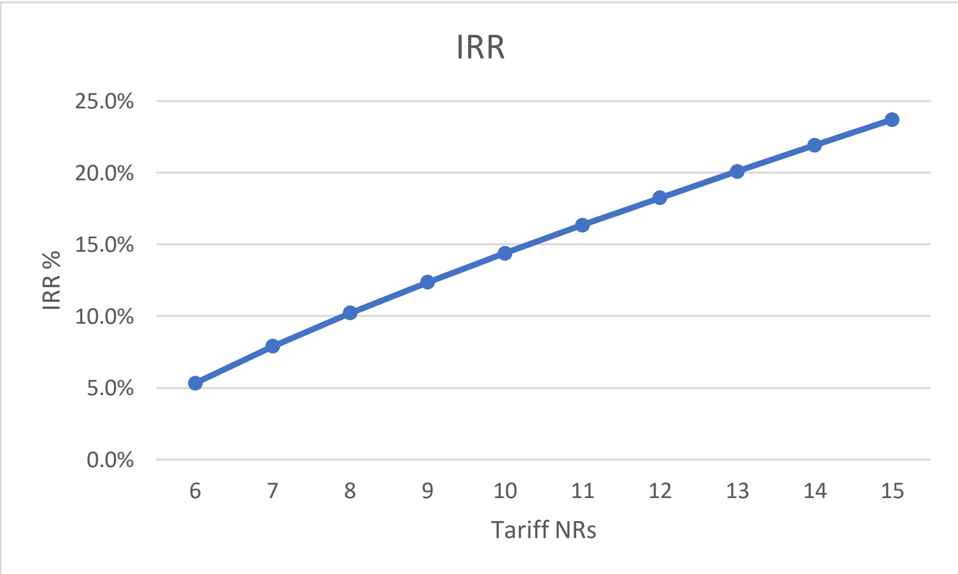

Figure 4.10: Internal Rate of Return for the plant.

Since the IRR for the tariff rate, the company is paying to utility company is 16.5% greater than the discount rate, the Solar PV plant is economically very good.

4.2.3 Levelized cost of electricity

The LCOE variation with Discount rate for the plant is shown in the figure 20.

The more Discount rate increase the LCOE of the plant.The LCOE at the discount rate of 10% is NRs. 7.91/kWh which is below the tariff rate that the company pay for utility energy consumption. The LCOE of the plant for discount rate of 8% and 12% is NRs. 7.05/kWh and NRs. 8.83/kWh respectively. The LCOE of the plant for discount rate above 8% is above the NRs. 7.3/kWh which is the utility company paying to the Utility scale energy company. Thus, if the company is paying below NRs7.3/kWh as paying to utility scale energy company, the project may not be feasible.However, since the company is only reducing the energy consumption from utility with tariff rate of NRs. 11.1/kWh, the solar power plant is feasible.

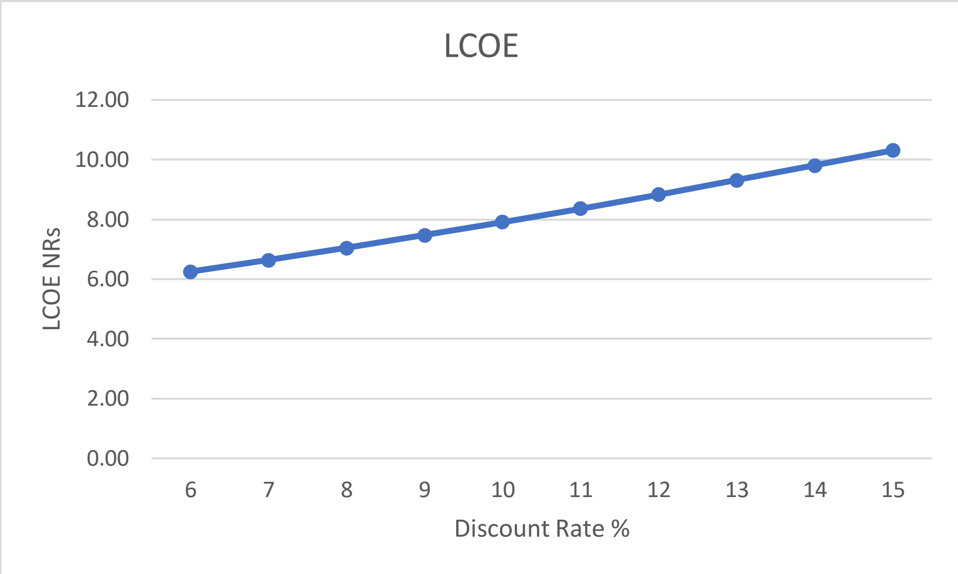

Figure 4.11: Variation of LCOE over Discount rate for the plant.

4.2.4 Monthly Bill Saving

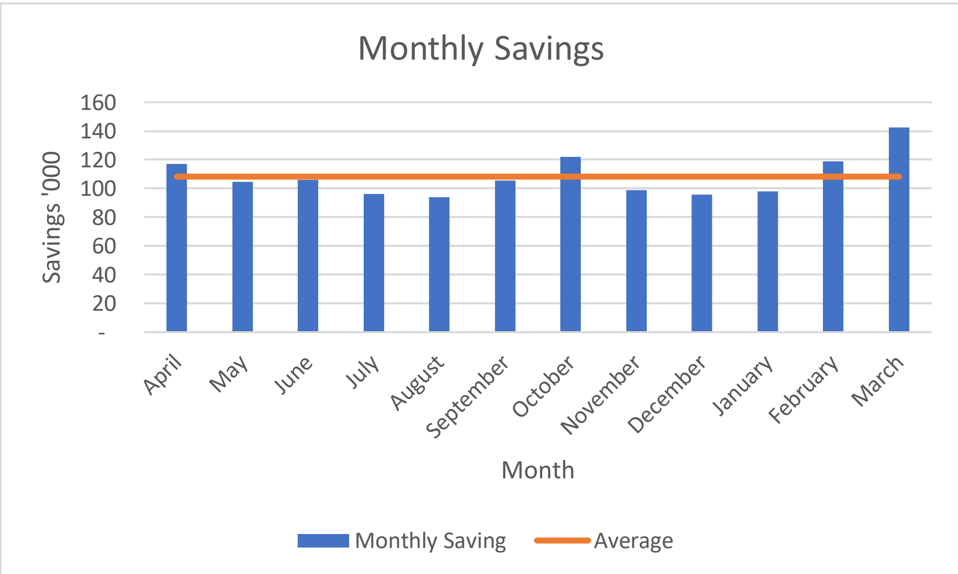

Figure 4.12: Monthly Bill Savings by the plant

The monthly Bill saving by the plant is shown in the figure 21. The average monthly bill saving is 108 thousand NRs. The highest bill saving is in the month March and lowest in the month August as the Energy generation. The saving is below average in the month May, June, July, August, September, November, December and January. The saving is above the average rest of the months. The highest saving is about 143 thousand and lowest is 94 thousand.

4.2.5 Payback Period

The Payback Period for the plant is about 5.44 years by simple payback period method calculation. However, the discounted payback period method calculation shows the payback period is higher. The discounted payback period is calculated by variation the tariff rate at fixed discount rate. The DPBP at the discount rate 10% for the tariff rate of NRs 11.1/kWh is about 8.2 years. The more the tariff rate, less will be the DPBP.

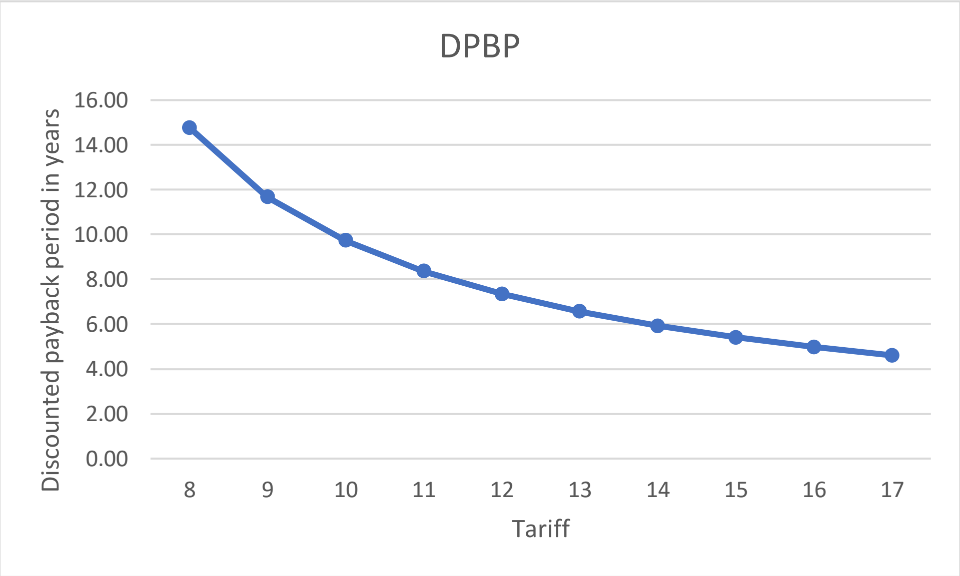

Figure 4.13: Variation of DPBP over Tariff rate for the plant.

The variation of the DPBP over the tariff rate is shown in the Figure 22. As the tariff rate or feed in tariff to the company is higher the DPBP is lesser. The DPBP will be more than the 15 years for the tariff rate of 7.3kWh/kWh which is the utility company pays to the utility scale Solar PV power plant in Nepal.

4.3 Comparative Economic analysis for Case I and Case III

There is Energy generation difference between the simulation Cases. The simulation considering all the PV modules installed in the thirty-degree tilt and zero azimuthhave quite higher energy generation than the simulation considering PV modules installed as in the existing site as shown in the table 10. This energy generation difference may differ in the economic parameters of these two cases. Assuming the difference in energy generation between these two cases shall be similar in actual scenario, the economic parameters with this energy generation difference are calculated. Since NPV is positive for existing case and IRR is higher than discount rate for existing case, the power plant is feasible. But the LCOE and DPBP can be little improved than the existing case. So, these two parameters are calculated for the energy generation difference.

4.3.1 Investment for Case I

For the installation of the PV modules in the thirty-degree tilt and zero-degree azimuth, there will be increment in the investment than existing one for the Solar frame. The increment of the height of vertical frame canobtain requirement of case I. Since the frame investment is 9% of the total investment as shown in the figure 10, the increment in investment for the case is negligible. However, assuming approximately 20% (may be higher or lower in real scenario) of frame cost will be requirement, the total investment increment is about 1.8% of total investment that will be about NRs 0.13million. The total investment requirement for the case I will be approximately NRs. 7.2 million. Thus, assuming the initial investment for the plant considering all the PV modules installation in slanted roof as in case I as NRs. 7.2 million, the LCOE and DPBP are calculated. The variation of these parameters is compared with existing one.

4.3.2 Levelized Cost of Electricity improvement

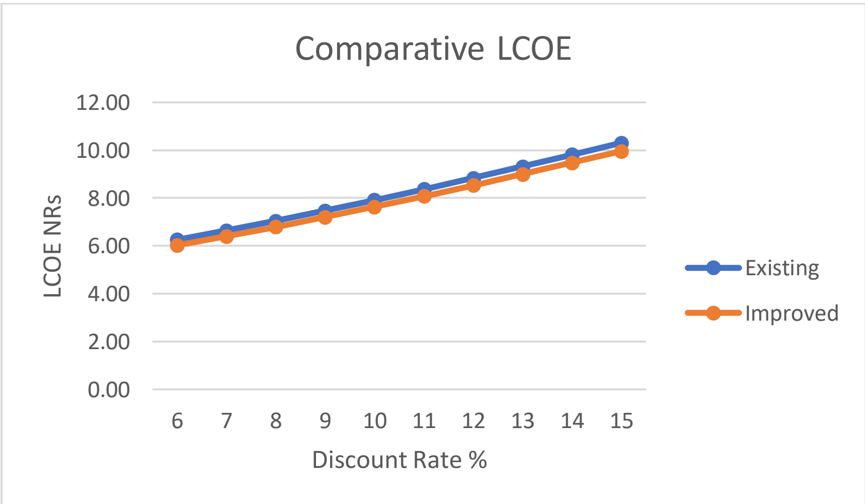

Figure 4.14: LCOE improvement

If the solar PV modules are installed as in flat roof that is the tilt angle and orientation is thirty-degree and zero-degree respectively, the LCOE will reduce by NRs. 0.28/kWh. The LCOE at 10% discount rate will be NRs. 7.63/kWh reduced from NRs. 7.91/kWh. The figure 4.14 shows the variation of the existing and improved LCOE over the different discount rate. The more the discount rate more will be the improved LCOE.

4.3.3 Payback Period improvement

The simple payback period for the case will be 5.27 years which is two months earlier. But discounted payback period at tariff rate of NRs. 11.10/kWh is 7.6 years. This is about 7 months earlier than the existing case. The variation of the DPBP over different tariff rate is shown in figure 24. The lower the tariff rate DPBP is higher. However, the DPBP is improved and lower the period at the tariff rate the consumer is paying. Thus, the installation as of the system with all the PV modules on tilt angle of 30 degree and 0-degree azimuth is better than the existing one.

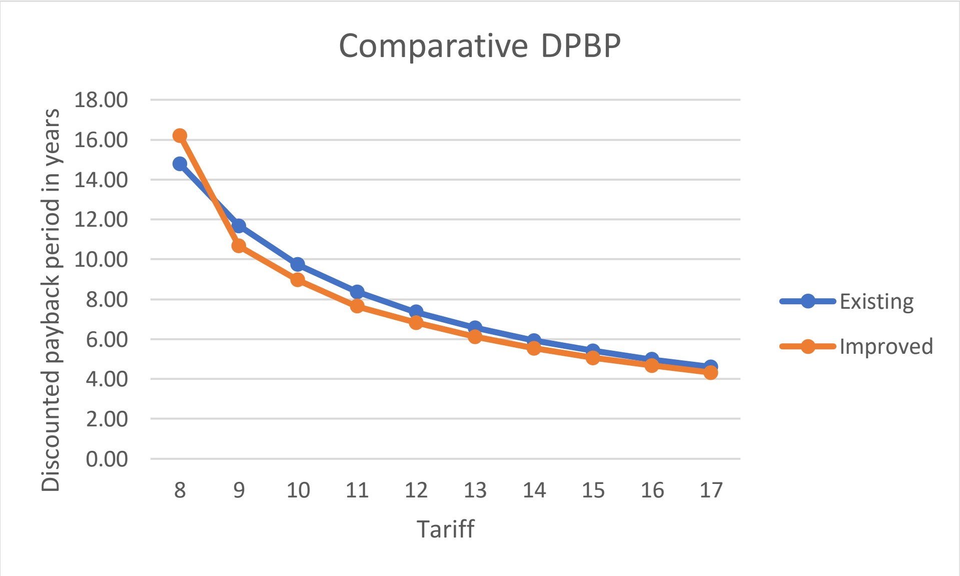

Figure 4.15: DPBP Improvement

However, the existing system is better in the case of tariff less than the NRs 8.5/kWh as the DPBP is lesser.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The conclusion of this research on the Performance analysis of 100kWp rooftop solar PV power plant at Chhauni Complex of Nepal Telecom are as follows:

The Performance parameters Energy Generation (Eac), Final yield (Yf), Reference Yield (Yr), Performance Ratio (PR), Capacity Utilization Factor (CUF) and System Efficiency for the existing system or actual generating plant are 9.75MWh/month or 325kWh/day, 3.2kWh/kW/day, 4.5kWh/m^2/day, 72%, 13.4%,13.6% respectively.

The Performance parameters Energy Generation (Eac), Final yield (Yf), Reference Yield (Yr), Performance Ratio (PR), Capacity Utilization Factor (CUF) and System Efficiency for the Simulation considering PV modules installed as in the site (Case III) are 12.63MWh/month or 410kWh/day, 4.1kWh/kW/day, 4.9kWh/m^2/day, 84%, 17.1%, 16.3% respectively.

Similarly, for the simulation Case I and Case II the performance parameters Energy Generation (Eac), Final yield (Yf), Reference Yield (Yr), Performance Ratio (PR), Capacity Utilization Factor (CUF) and System Efficiency are respectively 13.14MWh and 12.62MWh, 4.28kWh/kW/day and 3.85kWh/kW/day, 5.06kWh/m^2/day and 4.58kWh/m^2/day, 84% and 84%, 17.8% and 16.4% and 16.4% and 17.5%.

The Performance parameters shows the simulation considering all PV modules installed at the tilt 30° and azimuth 0° (case I) is better amongst the studied cases. The case II and case III have no significant differences in most of the parameters.

The NPV, IRR, LCOE, DPBP, Monthly savings, Annual Savings for the system are NRs.3.39 million, 17%, NRs. 7.92/kWh, 8.2 years, NRs. 108,000 and NRs. 1.3 million respectively at discount rate of 10% for project life of 25 years and tariff rate NRs. 11.10/kWh.

The installation of the system in slanted roof as in flat roof that is all PV modules installed in tilt 30° and azimuth 0°, the LCOE and DPBP reduced to NRs. 7.63/kWh and 7.6 years. Annually NRs. 68,000 additional saving can be made for the installation of PV in this case.

Annual Bill savings is reflection of the annual Energy Generation, thus, the annual savings for the simulation case II and simulation case III make no difference. However, the other economical parameters shall be better since little investment on frame can be minimized on case II simulation.

5.2 Recommendation

i. The little more investment on frame shall be done such that all PV modules can be installed all facing 0^o azimuth and 30^o inclination.

ii. The system frame design shall be done considering the probable shading loss and surrounding removable shading objects shall be removed for more generation.

iii. All the barren roof space can be used for grid tied Solar PV Plant. The Feed in tariff for the such low scale or roof-top shall not reduce from energy consumption tariff since the DPBP is higher for lower tariff rate.

iv. Since the LCOE is higher for higher discount rate, the subsidy on interest rate shall be provided for the green energy promotion.

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APPENDIX A: Irradiance Data Sample Obtained from DHM for month April

Day	W/m^2																							
	12AM	1AM	2AM	3AM	4AM	5AM	6AM	7AM	8AM	9AM	10AM	11AM	12PM	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM	10PM	11PM
1	0	0	0	0	0	0	23	164.3	382.7	625	812	955.1	966.7	828.9	633.8	298.9	136.7	35.9	8.9	0	0	0	0	0
2	0	0	0	0	0	0	32	204.6	442.2	675.2	874.2	948.9	949.2	862.3	739.9	475.4	177	66	9.7	0	0	0	0	0
3	0	0	0	0	0	0	34.3	212.3	460.4	691.1	858	946.9	950.8	860	742	571.1	316.7	136.4	8.5	0	0	0	0	0
4	0	0	0	0	0	0	26.5	152.2	333	539	700.3	808.7	791.9	713.7	585.1	404.3	230.3	84.1	7.5	0	0	0	0	0
5	0	0	0	0	0	0	22.7	116.4	269.4	412.5	559.6	652.2	667.3	610.6	481.2	343.8	179.5	61.5	5.2	0	0	0	0	0
6	0	0	0	0	0	0	18.8	105.8	234.5	364.4	481.9	563.1	579.9	541.4	446.2	307.8	161.8	58.7	5.4	0	0	0	0	0
7	0	0	0	0	0	0	24.7	125.1	267.6	450.4	598.5	670.8	694.2	683.3	575.6	438.3	317.2	111.5	5.9	0	0	0	0	0
8	0	0	0	0	0	0	30.1	154.6	350.7	540.3	748.5	935.8	999.9	916.9	770.7	551.2	175.2	107.8	9.4	0.6	0	0	0	0
9	0	0	0	0	0	0	43.1	208.1	429.9	647.2	712.2	709.5	910.4	873.3	279.6	352.5	132.3	48.6	2.9	0	0	0	0	0
10	0	0	0	0	0	0	49.2	233.5	480.7	684.1	853.8	949	972.9	930.4	814.9	620.5	415.1	189.8	20.4	0	0	0	0	0
11	0	0	0	0	0	0.1	59.2	232.4	468.2	689.1	860.1	983.9	956.5	895.7	741.9	513.2	310.9	114.3	12.9	0	0	0	0	0
12	0	0	0	0	0	0	41	88.2	188.5	365.7	671	785.1	803.4	728.8	597.3	417	255	101.2	10.7	0	0	0	0	0
13	0	0	0	0	0	0	32	144.8	302.9	480.9	623.2	734.7	792.1	759.7	551.8	241.1	62.3	44	3.2	0	0	0	0	0
14	0	0	0	0	0	0.1	38.3	171.5	349.8	512.5	661	735.3	760.9	694.7	562.4	393.6	250.3	98.7	11.8	0	0	0	0	0
15	0	0	0	0	0	0.1	34.5	152.9	332.9	444.7	552.8	701.7	789.3	684	543.1	458.9	341.6	141.6	12.4	0	0	0.2	0	0
16	0	0	0	0	0	0.1	44.8	168.1	353.4	543.7	675.4	512.6	104.3	65.7	129.5	411.5	8.6	0.4	1.9	0.1	0	0	0	0
17	0	0	0	0	0	0.3	42.3	185.3	380	575.4	732.9	836.2	783.5	823.4	732.5	569.7	255.1	58	2.4	0	0	0	0	0
18	0	0	0	0	0	0.5	69	254.4	501.6	706.9	868.7	1036.5	1058.7	992.2	874.9	709.2	453.7	47.9	0.4	0.1	0	0	0	0
19	0	0	0	0	0	0.9	74.7	278.2	502.9	733.2	902.6	997.4	999.6	951.4	832.5	655.6	387.5	169.7	29.4	0	0	0	0	0
20	0	0	0	0	0	0.7	71.9	265.5	493	717.1	882.6	975.5	946.4	940.6	802.4	589.5	354.2	111.9	18.9	0	0	0	0	0

21	0	0	0	0	0	0.4	57.9	137.5	95.9	183.4	125.1	141.8	268.9	232.5	143.4	153.6	196.4	94.4	8.4	0	0	0	0	0
22	0	0	0	0	0	0	1.1	16.2	39.6	246	186.7	595.1	942.6	962.4	904.7	704.9	484.4	230.9	39.1	0	0	0	0	0
23	0	0	0	0	0	1.6	115.5	344.6	595.7	802.5	950.1	1056.8	1084.1	968.3	888	703.2	474	227.3	36.5	0	0	0	0	0
24	0	0	0	0	0	1.4	90	340.9	501.7	537.6	895	776	907	981.1	878	692	470.2	199.5	23.6	0	0	0	0	0
25	0	0	0	0	0	2.2	102.6	321	563.4	783.8	933.5	1015.7	1033.3	992.3	857.2	652.8	245.3	110.6	19.9	0	0	0	0	0
26	0	0	0	0	0	1.6	87	299.6	515.5	726.3	886.4	980.3	953.5	890.2	779.7	540.8	398.4	175	23.7	0	0	0	0	0
27	0	0	0	0	0	1.5	64.4	225.1	430.5	631.6	792.6	877.9	899.6	814.9	613.9	474.2	320.8	137.3	23.3	0	0	0	0	0
28	0	0	0	0	0	2.1	61.8	208.1	397.8	577.9	730.8	816	868.8	796.9	651.9	479.4	308.9	148.3	21.5	0	0	0	0	0
29	0	0	0	0	0	1.1	52.2	187.3	357.7	530.4	661.5	769.1	430.7	783	108.4	0.2	0.1	2.4	2.6	0	0	0	0	0
30	0	0	0	0	0	1.5	32.4	152.3	244.7	583.1	799.8	831.3	829.5	592.8	608.7	466.5	416.3	84.2	6.1	0	0	0	0	0

APPENDIX B: Daily Energy Generation Data Collection from the site

Day	April	May	June	July	August	September	October	November	December	January	February	March
1		225.03	321.72	80.65	428.99	423.26	296.54	340.00	284.72	336.41	268.72	455.89
2	169.89	148.91	523.64	94.71	283.52	382.11	289.45	150.61	202.91	300.36	281.79	488.75
3	476.84	442.52	538.40	273.90	343.62	291.08	366.21	322.90	161.78	331.36	256.93	461.91
4	372.55	209.32	414.47	297.59	151.30	531.57	341.09	380.38	309.39	332.71	30.35	490.35
5	253.26	376.76	510.75	262.65	293.00	428.53	467.21	291.27	343.40	240.09		474.77
6	247.28	270.88	522.58	446.47	376.91	218.16	405.68	353.00	276.94	265.47	443.91	450.65
7	328.63	230.69	527.41	302.76	285.85	315.87	434.60	325.23	353.98	157.11	459.56	427.10
8	437.46	380.01	392.74	148.80	321.59	286.20	457.74	379.48	287.61	168.33	377.24	447.37
9	363.26	348.67	420.82	328.01	446.87	207.87	419.72	378.02	161.98	210.99	421.92	438.57
10	494.82	266.35	276.23	291.78	307.91	322.56	413.26	387.40	288.99	223.97	464.14	399.95
11	461.10	221.38	283.23	211.34	357.21	402.35	432.89	377.12	303.88	326.68	370.96	427.21
12	345.23	196.36	233.80	286.86	243.50	457.77	428.86	366.14	306.73	178.45	470.14	413.60
13	310.37	280.98	166.11	386.17	344.72	312.44	441.98	366.65	317.01	381.03	445.48	414.69
14	335.91	365.61	218.13	215.46	260.25	274.63	450.19	359.89	307.88	296.60	426.67	404.92
15	454.63	480.22	91.39	170.33	251.25	130.59	416.48	341.21	270.23	336.26	414.13	382.40
16	88.65	538.93	199.42	195.47	320.32	188.39	423.57	343.54	304.65	374.60	409.50	381.35
17	433.84	311.33	268.23	282.84	184.21	103.75	237.50	336.80	307.60	316.47	444.25	419.97
18	544.10	258.99	314.39	208.61	253.61	465.12	105.06	175.96	339.67	382.76	428.11	441.41
19	329.54	157.30	271.29	287.68	289.44	474.10	97.61	97.12	367.84	392.23	421.03	311.80
20	474.21	162.73	191.33	330.10	284.53	270.85	221.27	273.60	365.52	70.19	436.61	448.16
21	121.87	506.90	470.34	367.40	245.42	503.90	481.04	337.57	322.64	273.61	438.83	402.71
22	430.71	455.06	386.43	353.55	339.42	214.29	199.96	315.85	347.45	203.24	426.18	398.43
23	381.76	467.91	311.42	252.90	136.53	304.23	409.44	267.42	344.69	197.67	450.67	358.76
24	524.50	390.59	305.01	179.50	172.63	358.16	350.32	231.44	317.61	140.39	412.02	393.53
25	506.31	211.75	42.69	307.96	212.88	267.55	312.90	240.38	267.05	306.15	292.55	466.06
26	477.97	172.62	127.78	377.77	145.16	310.85	344.34	115.91	273.60	232.61	479.75	496.06
27	376.46	124.18	360.44	460.49	142.98	325.15	393.67	247.65	271.06	349.46	449.51	448.31
28	395.95	55.43	378.47	331.58	160.08	235.20	341.82	279.77	150.32	334.80	466.18	326.70

29	223.40	345.16	316.80	399.38	112.71	232.02	398.42	286.70	27.97	366.19		283.16
30	403.54	395.26	159.09		296.92	250.19	244.43	247.98	139.42	382.33		242.44
31		429.35			469.70		359.15		299.27	398.72		391.78

APPENDIX C:Detail PVsyst simulation Report for Case I

Project: Grid-Tied Roof top solar PV chhauni

Variant: New simulation variant

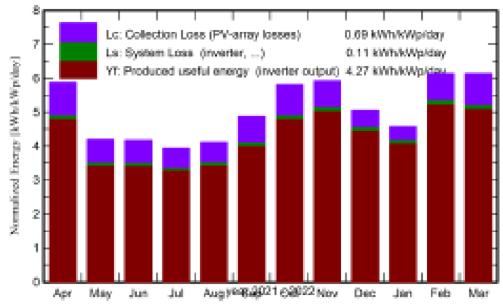
PVsyst V7.2.11
VC0, Simulation date:
31/08/22 17:43
with v7.2.11

Main results

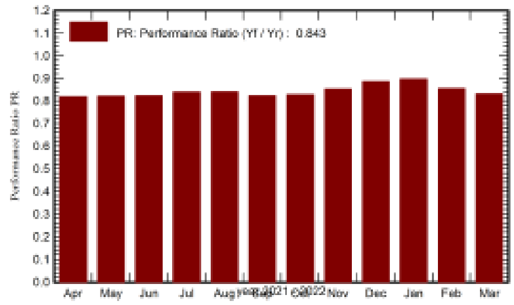
System Production

Produced Energy	157.6 MWh/year	Specific production	1557 kWh/kWp/year
		Performance Ratio PR	84.29 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	ratio
Apr. 21	174.5	70.11	23.48	176.5	173.5	14.99	14.63	0.819
May 21	140.9	73.41	25.12	130.0	126.8	11.10	10.82	0.822
June 21	140.1	72.85	23.57	125.2	122.0	10.71	10.45	0.824
July 21	133.3	78.95	23.53	122.0	119.0	10.62	10.36	0.839
Aug. 21	132.7	81.11	22.78	127.5	124.6	11.12	10.85	0.841
Sep. 21	137.7	64.18	22.30	146.6	143.9	12.55	12.24	0.824
Oct. 21	146.7	52.57	20.27	180.3	177.6	15.50	15.12	0.828
Nov. 21	127.6	39.49	14.93	177.7	175.4	15.70	15.33	0.852
Dec. 21	107.1	37.95	9.70	156.7	154.7	14.38	14.05	0.885
Jan. 22	104.3	46.94	7.87	141.9	139.8	13.19	12.88	0.897
Feb. 22	132.9	42.25	12.88	172.0	169.4	15.24	14.88	0.854
Mar. 22	164.5	54.32	17.75	190.6	187.7	16.44	16.04	0.831
Year	1642.1	714.11	18.70	1847.1	1814.3	161.53	157.65	0.843

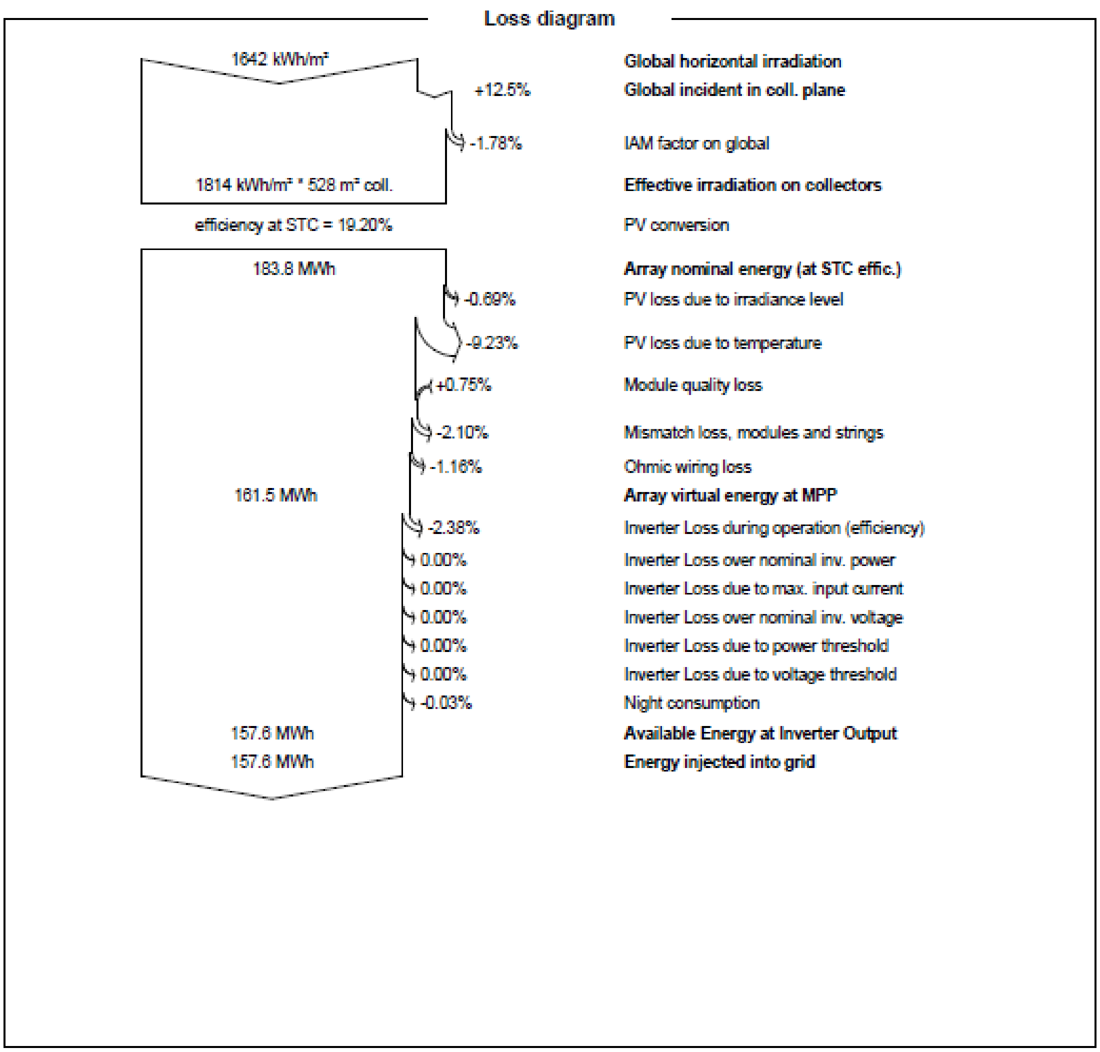
Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Project: Grid-Tied Roof top solar PV chhauni

Variant: New simulation variant

PVsyst V7.2.11
VC0, Simulation date:
31/08/22 17:43
with v7.2.11



APPENDIX D: Detail PVsyst Simulation Report for Case II

Project: Grid-Tied Roof top solar PV chhauni

Variant: New simulation variant

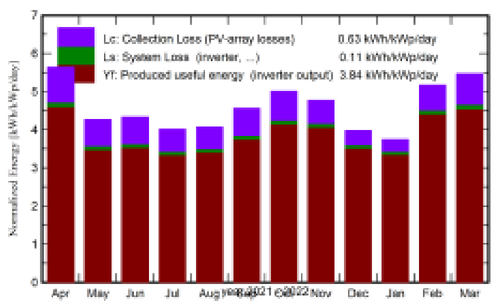
PVsyst V7.2.11
VC1, Simulation date:
31/08/22 17:41
with v7.2.11

Main results

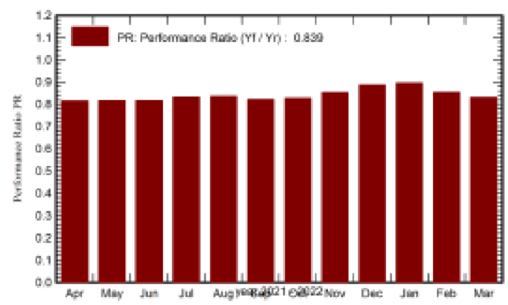
System Production

Produced Energy	151.4 MWh/year	Specific production	1402 kWh/kWp/year
		Performance Ratio PR	83.93 %

Normalized productions (per installed kWp)



Performance Ratio PR



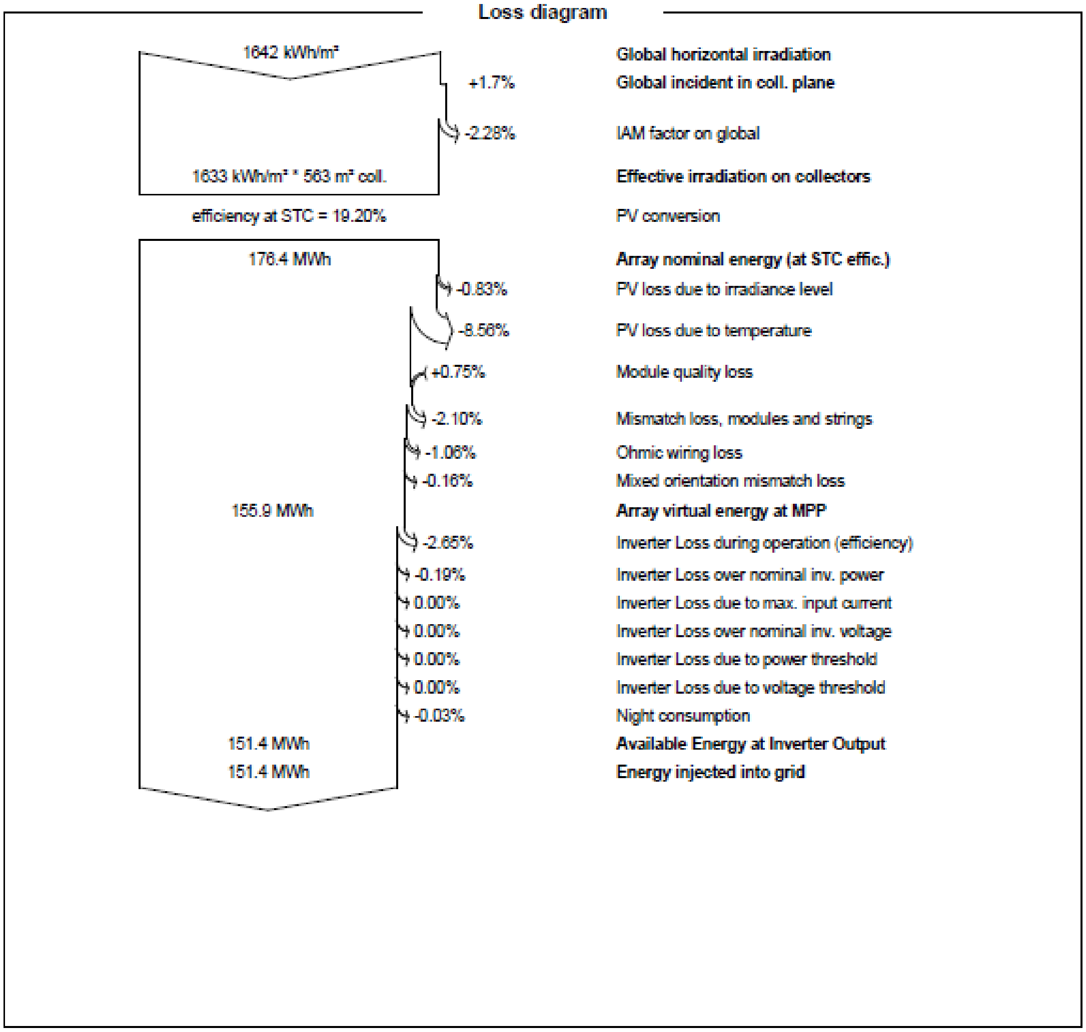
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
Apr. 21	174.5	70.11	23.48	169.2	166.1	15.33	14.91	0.816
May 21	140.9	73.41	25.12	132.2	129.1	12.00	11.66	0.816
June 21	140.1	72.85	23.57	130.0	126.8	11.79	11.46	0.816
July 21	133.3	78.95	23.53	124.5	121.5	11.52	11.19	0.833
Aug. 21	132.7	81.11	22.78	126.3	123.4	11.74	11.41	0.836
Sep. 21	137.7	64.18	22.30	136.8	133.8	12.51	12.16	0.823
Oct. 21	146.7	52.57	20.27	155.4	151.9	14.27	13.89	0.828
Nov. 21	127.6	39.49	14.93	143.1	139.7	13.53	13.19	0.853
Dec. 21	107.1	37.95	9.70	123.1	119.8	12.08	11.78	0.886
Jan. 22	104.3	46.94	7.87	115.9	112.8	11.50	11.21	0.896
Feb. 22	132.9	42.25	12.88	144.7	141.4	13.69	13.34	0.854
Mar. 22	164.5	54.32	17.75	169.6	166.2	15.65	15.23	0.832
Year	1642.1	714.11	18.70	1670.6	1632.6	155.61	151.43	0.839

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram



APPENDIXE:Detail PVsyst Simulation Report for Case III

Project: Grid-Tied Roof top solar PV chhauni

Variant: New simulation variant

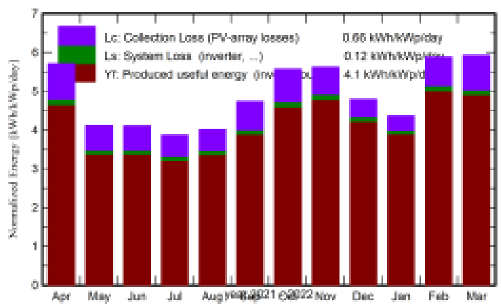
PVsyst V7.2.11
VC2, Simulation date:
31/08/22 20:01
with v7.2.11

Main results

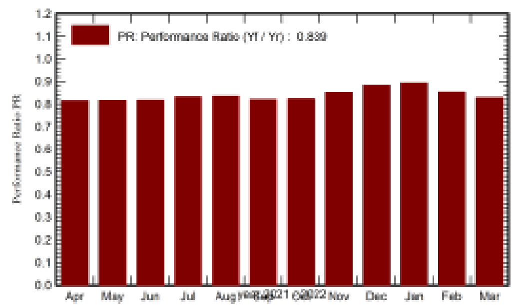
System Production

Produced Energy	151.5 MWh/year	Specific production	1496 kWh/kWp/year
		Performance Ratio PR	83.89 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

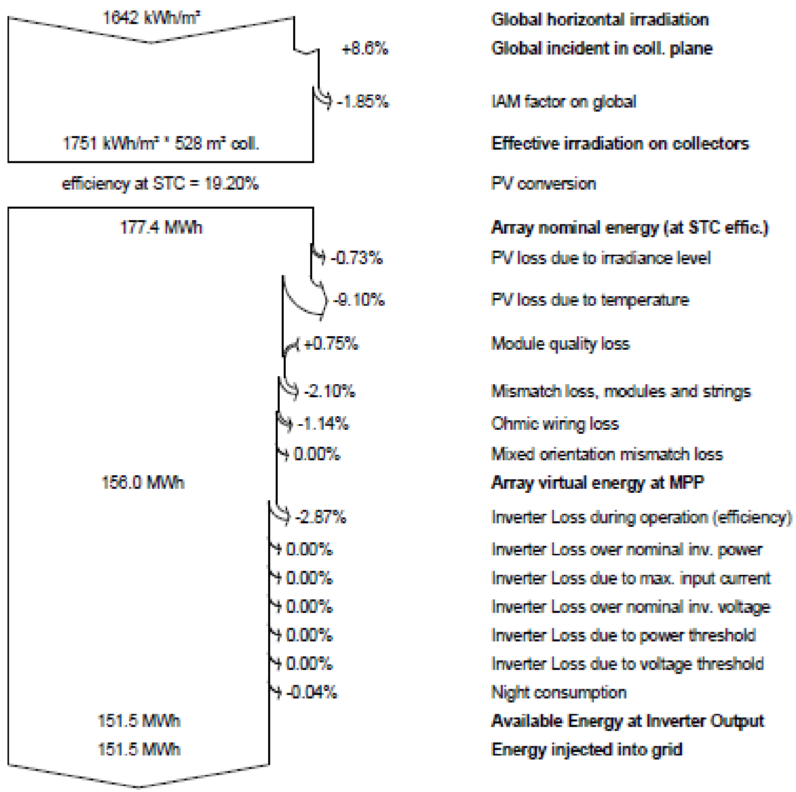
	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
Apr. 21	174.5	70.11	23.48	171.4	168.5	14.58	14.15	0.815
May 21	140.9	73.41	25.12	127.9	124.9	10.93	10.57	0.816
June 21	140.1	72.85	23.57	123.5	120.5	10.57	10.23	0.818
July 21	133.3	78.95	23.53	119.9	116.9	10.44	10.10	0.832
Aug. 21	132.7	81.11	22.78	124.8	121.9	10.88	10.54	0.834
Sep. 21	137.7	64.18	22.30	142.2	139.6	12.19	11.82	0.821
Oct. 21	146.7	52.57	20.27	172.9	170.1	14.87	14.44	0.825
Nov. 21	127.6	39.49	14.93	168.9	166.4	14.94	14.54	0.850
Dec. 21	107.1	37.95	9.70	148.6	146.3	13.64	13.28	0.883
Jan. 22	104.3	46.94	7.87	135.2	132.8	12.57	12.23	0.893
Feb. 22	132.9	42.25	12.88	164.7	162.0	14.61	14.22	0.852
Mar. 22	164.5	54.32	17.75	183.6	180.6	15.84	15.41	0.829
Year	1642.1	714.11	18.70	1783.6	1750.6	156.05	151.50	0.839

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

PVsyst V7.2.11
VC2, Simulation date:
31/08/22 20:01
with v7.2.11

Loss diagram



APPENDIXF: Time of Day (ToD) Tariff Rate screenshot

3. Time of Day (ToD) Tariff Rate

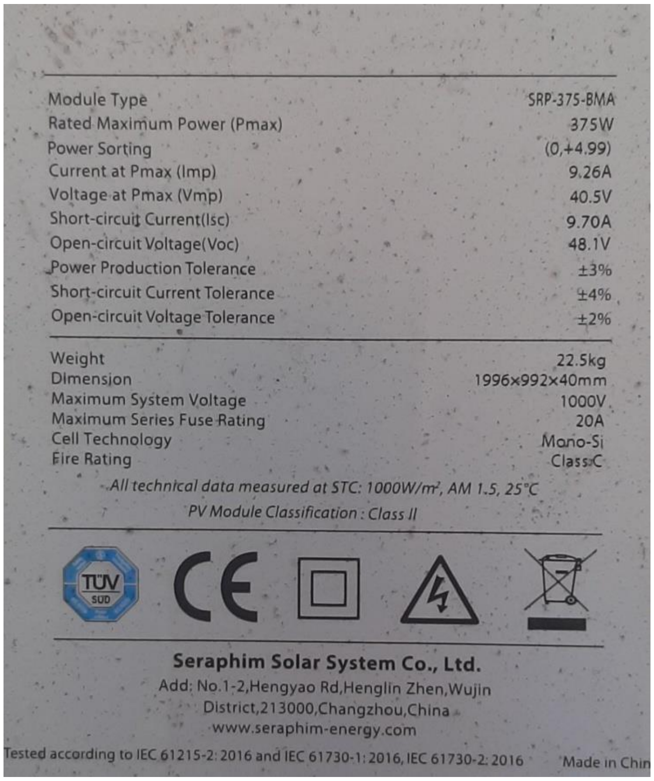
3.1 Tariff Rate from Baishakh to Mangsir

Consumer Category	Demand Charge Nrs./ KVA/ month	Peak Time (17.00-23.00)	Off Peak Time (23.00-5.00)	Normal time (5.00-17.00)
A. High Voltage				
1. Industrial (132 kV)	230.00	10.00	4.65	8.20
2. Industrial (66 kV)	240.00	10.10	4.75	8.30
B. Medium Voltage (33 KV)				
1. Industrial	250.00	10.20	5.25	8.40
2. Commercial	315.00	12.30	6.75	10.80
3. Non-Commercial	240.00	13.20	7.00	12.00
4. Irrigation	-	6.30	2.00	3.00
5. Water Supply				
a) Community Water Supply	-	6.20	3.10	4.60
b) Other Water Supply	150.00	10.20	5.25	8.40
6. Transportation				
a) Public Transportation (Charging Station)	230.00	7.00	3.70	5.50
b) Other Transportation	255.00	9.35	3.70	8.40
7. Street Light	80.00	8.40	3.50	4.20
C. Medium Voltage (11 KV)				
1. Industrial	250.00	10.50	5.40	8.55
2. Commercial	315.00	12.60	6.90	11.10
3. Non-commercial	240.00	13.50	7.15	12.25
4. Irrigation	-	6.40	2.00	3.10
5. Water Supply				
a) Community Water Supply	-	6.30	3.40	4.70
b) Other Water Supply	150.00	10.50	5.40	8.50
6. Transportation				
a) Public Transportation (Charging Station)	230.00	7.15	4.20	5.60
b) Other Transportation	255.00	9.65	4.20	8.50

3.2 Tariff Rate from Paush to Chaitra

Consumer Category	Demand Charge Nrs. /KVA/ month	Peak Time (17.00 - 23.00)	Normal Time (23.00 - 17.00)
A. High Voltage			
1. Industrial (132 kV)	230.00	10.00	8.20
2. Industrial (66 kV)	240.00	10.10	8.30
B. Medium Voltage (33 KV)			
1. Industrial	250.00	10.20	8.40
2. Commercial	315.00	12.30	10.80
3. Non-Commercial	240.00	13.20	12.00
4. Irrigation	-	6.30	3.00
5. Water Supply			
a) Community Water Supply	-	6.20	4.60
b) Other Water Supply	150.00	10.20	8.40
6. Transportation			
a) Public Transportation (Charging Station)	230.00	7.00	5.50
b) Other Transportation	255.00	9.35	8.40
7. Street Light	80.00	8.40	4.20
C. Medium Voltage (11 KV)			
1. Industrial	250.00	10.50	8.55
2. Commercial	315.00	12.60	11.10
3. Non-commercial	240.00	13.50	12.25
4. Irrigation	-	6.40	3.10
5. Water Supply			
a) Community Water Supply	-	6.30	4.70
b) Other Water Supply	150.00	10.50	8.50

APPENDIX G: Technical Specification of Solar PV module and Inverter



Technical Data	Sunny Tripower CORE1
Input (DC)	
Max. generator power	75000 Wp STC
Max. input voltage	1000 V
MPP voltage range / rated input voltage	500 V to 800 V / 670 V
Min. input voltage / start input voltage	150 V / 188 V
Max. operating input current / per MPPT	120 A / 20 A
Max. short circuit current per MPPT / per string input	30A / 30A
Number of independent MPPT inputs / strings per MPP input	6 / 2
Output (AC)	
Rated power (at 230 V, 50 Hz)	50000 W
Max. apparent AC power	50000 VA
AC nominal voltage	220 V / 380 V 230 V / 400 V 240 V / 415 V
AC voltage range	202 V to 305 V
AC grid frequency / range	50 Hz / 44 Hz to 55 Hz 60 Hz / 54 Hz to 65 Hz
Rated power frequency / rated grid voltage	50 Hz / 230 V
Max. output current / Rated output current	72.5 A / 72.5 A
Output phases / AC connection	3 / 3-(N)-PE
Power factor at rated power / Adjustable displacement power factor	1 / 0.0 leading to 0.0 lagging