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Techno-Economic Analysis of 64.6 kWp Grid Tied Solar System

A Case Study of Nepal Telecom, Sundhara, Kathmandu

by

Sajendra Man Bajracharya

A THESIS

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DEPARTMENT OF MECHANICAL ENGINEERNG

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "Techno-Economic Analysis of 64.6 kWp Grid Tied Solar System: A Case Study of Nepal Telecom, Sundhara, Kathmandu" submitted by Sajendra Man Bajracharya, in partial fulfillment of the requirements for the degree of Master of Science in Technology and Innovation Management.

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ABSTRACT

In this thesis, technical and economic performance analysis was performed for 64.6 kWp grid-tied solar system installed at Nepal Telecom, Sundhara, Kathmandu. Firstly, the system was simulated in PV syst software with NASA-SEE satellite data and the real field data were collected from the site. The data has been logged into the data logger and analyzed in detail by retrieving using web interface. Over the duration of the study, various climatic and electrical parameter of PV system were collected and analyzed. The performance of grid-tied solar system has been analyzed by calculating technical parameters like daily/monthly electricity generation, final yield, reference yield, performance ratio ,capacity utilization factor, overall system efficiency, normalized energy losses; economic parameters like annual/monthly savings, discounted payback period, net present value(NPV), internal rate of return(IRR) and levelized cost of electricity (LCOE).

The analysis of data shows that this 64.6 kWp grid-tied solar system would generate daily 219 kWh of electricity on average. The reference yield, final yield, performance ratio, capacity utilization factor, overall system efficiency and normalized system losses of the system were 3.94 kWh/kW/day, 3.38 kWh/kW/day, 0.859, 14.09%, 15.06% and 0.56 kWh/kW/day respectively. This study also showed simulated values of energy generation were relatively higher (14.65%) compared to measured generation. The system will save annually 1.60 million Nepalese Rupees and has discounted payback period of 5.2 years. NPV, IRR and LCOE of the system were respectively 2.06 million Nepalese Rupees, 17.22 % and NRs.17.97/kWh. Hence, it can be concluded grid tied solar system is gradually becoming technically and economically feasible in Nepal.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AEPC	Alternative Energy Promotion Centre
CUF	Capacity Utilization Factor
CES	Center for Energy Studies
DG	Diesel Generator
EIA	Environment Impact Assessment
EU	European Union
IEA	International Energy Agency
IOE	Institute of Engineering
JICA	Japan International Cooperation Agency
LDC	Least Developed Country
MoE	Ministry of Energy
MPPT	Maximum Power Point Tracker
NEA	Nepal Electricity Authority
NPC	National Planning Commission
NREL	National Renewable Energy Laboratory
NT	Nepal Telecom
PR	Performance Ratio
R&D	Research and Development
SHS	Solar Home Systems
STP	Standard Temperature and Pressure
SUPSI	University of Applied Sciences and Arts of Southern Switzerland
TU	Tribhuvan University

UNDP	United Nations Development Programme
WB	World Bank

1. CHAPTER ONE: INTRODUCTION

1.1. Background

Nepal is rich in water, solar, wind and biomass resources, but due to the lack of dissemination of innovative technical knowledge and enough financial provision, the country is unable to utilize these resources properly for the benefit of urban and rural livelihoods (GoN, 2019). In Nepal, around 2.8 % of energy supply come from grid electricity, and is primarily used for lighting purpose only (ADB, 2017). Hence, most of the people are dependent on other energy sources, such as fuel wood, agriculture residue, coal, and fossil fuels, to cover their needs. Also Nepal imported more than one third of the electricity (42.3%) from India last year, thereby implying major energy security risks (NEA, 2019).

Given that solar is the second most abundant and preferred source of energy for Nepal after hydro, developing the solar PV industry is justifiable. As for other models within solar PV, such as distributed solar home systems (SHSs) and solar micro-grids, Nepal has seen some development in those sub-sectors already, but the impacts from those models were limited. Distributed solar home systems took off in the last decade but the model suffered from severe implementation issues and they were limited to just powering a few bulbs in the rural households (GoN, 2010). Solar micro-grids turned out to be vastly expensive and unsustainable without 80+% of the total cost in grants (UN, 2014). The only other model that can achieve large scale solar PV development is utility-scale solar, as in the case for India today. However, given that Nepal has significant transmission constraints, achieving large utility scale solar becomes less feasible (ADB, 2017).

Proliferation of grid-tied solar PV solutions would mean that Nepal, currently among the poorest in the world, is able to attain a reliable, diversified energy system that is able to provide power to even the remotest parts of the country, hence ensuring better living standards all of its 30 million people. Nepal’s goal is to graduate from the Least Developed Country (LDC) status by the year 2022, and energy is one of the critical ingredients to attain the goal. The government also plans to achieve 99% electrification rate by the year 2030, and it cannot achieve that by relying on hydro plants that can easily take a minimum of five years to construct (NPC, 2017).

1.2. Problem Statement

A commercial office of Nepal Telecom at Sundhara, Kathmandu is the central control unit for landline/mobile phones, international calls, and revenue collection. This office requires at least about 600 to 700 kW of electric energy throughout 24 hours a day. With the sensitivity of the site, the office is provided electricity with dedicated feeder, hence it is charged with special price of Rs.18.50/kWh during day times (5:00 to 17:00) by Nepal Electricity Authority (NEA). Thereby, this office pays about NRs.40 million for electricity annually for daytime load. Apart from this, the office also uses diesel generators of capacity 1250 KVA in case of intermittent power cut/ emergencies, emitting pollutants and hence causing environmental pollution.

In order to minimize annual electricity costs & utilize its roofs space, it came up with an idea of installing Grid-Tied Solar System at its office roofs. Post installation, any kind of performance evaluation of the system is yet to be done. It is still unknown whether the objective of realization of grid tied solar system at the site has been fulfilled or not. So, this thesis focused on technical and economic performance analysis of the system in order to examine whether the idea has achieved the objectives it is supposed to. With the successful operation of this system at Sundhara, Kathmandu, Nepal Telecom has plans to replicate it at their other sites. This research could be a resource material to the organization and other commercial institutions about what to expect technically, economically from a grid tied solar system, what measures to be taken in future installations to make it more efficient.

1.3. Rationale

1.3.1. Need

The purpose of this research is to evaluate technical and economic performance parameters of grid-tied solar system under real climatic conditions in order to promote grid tied solar system in the country. This will facilitate in determining accurate and consistent output from the system without over or under estimating performance of the system. This will enable in calculating realistic figures for financial returns, which will ultimately give a clear picture of output from the system to the stakeholders who are willing to implement the system.

1.3.2. Importance

At the current stage of economic development in the country, this study on Grid-Tied Solar Systems in Nepal carries following important benefits for the entire economy:

A. **Boost to the total energy supply**: Nepal imported more than one third (43.2%) of the electricity from India last year, thereby implying major energy security risks (NEA, 2019). Solar PV injection, therefore, has the power to minimize imports. Hydro, the major source of power for the country today, has long lead-times and cannot be constructed immediately to offset imports.

B. **Supply diversification**: Hydro covers almost 100% of the total domestic production. With climate change effects getting more visible in the Himalayan region, relying on hydro alone is highly risky (ADB, 2017). Solar PV in Nepal is such that it works perfectly to complement hydro generation, especially in winter months when the monsoon dependent rivers dry up.

C. **Improved trade balance**: Nepal today suffers from worsening trade balance due to high levels of power and fossil fuel imports (ADB, 2017). A stronger local energy generation therefore has the power to improve trade balance significantly. In addition, the current national goals to make electricity the primary source of energy support the need to develop solar PV industry in the country.

D. **Lower transmission congestion & losses**: Nepal's transmission network is outdated and is in no position to accommodate large power generation capacity addition that the government plans to achieve in the next 10 years. On-site solar PV generation therefore has the capacity to not only reduce pressure on transmission and distribution, but also reduce power losses that occur upon using the outdated infrastructure (losses are estimated to be up to 25%) (ADB, 2017).

E. **Higher energy access for rural consumers**: In a supply constrained country, if the large consumers consume less energy as a result of on-site solar PV, the rest of the country will have more power for access. The sole utility, Nepal Electricity Authority(NEA), has been slow to expand their transmission lines in the extreme parts of the country owing to the lack of adequate energy availability in the first place. A large portion of the rural population has been forced to live a subsistent life, with virtually no access to modern technology, due to the lack of electricity. Therefore, energy access in the villages could mean a steep improvement in the living standard and possibilities for rural enterprise development.

F. **Case study for optimal policy design**: In order to achieve a balanced energy system with diversified energy mix, it is important to develop the solar PV industry. On-site solar PV generation model is the quick and ideal solution for a country that suffers from significant infrastructure constraints. But to achieve a large scale PV development, policy makers are now in need of case studies that they can rely upon. This pilot project could lay the grounds for the development of conducive policies.

1.4. Objectives

1.4.1 Main Objective

The main objective of this thesis is to perform techno-economic analysis of 64.6 kWp Grid Tied Solar System at Nepal Telecom, Sundhara, Kathmandu.

1.4.2 Specific Objectives

In order to achieve main objective of the thesis, following specific objectives are developed:

1. To simulate 64.6 kWp grid tied solar system to determine technical parameters, i.e. total energy generated (E_{AC}), reference yield (Y_R),final yield (Y_F), performance ratio (PR), capacity utilization factor (CUF), overall system efficiency (η_{system}), normalized energy losses (L_T).
2. To determine measured technical parameters, i.e. total energy generated (E_{AC}), reference yield (Y_R), final yield (Y_F), performance ratio (PR), capacity utilization factor (CUF), overall system efficiency (η_{system}), normalized energy losses (L_T).
3. To compare simulated and measured technical parameters.
4. To perform economic analysis of 64.6 kWp grid tied solar system.

1.5 Scope of the work

Following are the scope of works of this research:

i. Collection of relevant data, daily/monthly energy generation.
ii. Simulate 64.6 kWp grid tied solar system with site parameters in software PV syst to determine technical parameters.
iii. Determine actual technical parameters for 64.6 kWp grid tied solar system.
iv. Compare simulated and actual technical performance parameters.
v. Perform economic analysis of 64.6 kWp of the grid tied solar system.

1.6 Limitations

i. This grid-tied solar system came into operation from March, 2019. So, only data of few months was available for analysis during this thesis.

ii. Due to the construction activity going around the office, solar panels were covered with thick layers of dust quickly. Dust factor has not been considered in the study.

2. CHAPTER TWO: LITERATURE REVIEW

2.1. Grid-Tied Solar System

Grid-Tied Solar System simply refers to the solar system that is directly connected to the electricity grid (IRENA, 2015). A Grid-Tied Solar System installed site can use electricity from the solar installation to operate its loads and, if that is not sufficient, any additional electricity required to operate the loads comes from the grid. In case the site does not use all the electricity from the solar system as it is generated, the surplus goes into the grid for the utility to pass on to other customers. In general, this system is best suited for the sites like schools, hospitals, hotels, banks, offices, industries i.e. institutions which have day loads.

In order to encourage commercial institutions to add grid-tied solar system, Nepal Electricity Authority (NEA), sole supplier of electricity in Nepal, has already introduced "Net Metering" system (GoN, 2017). In this system, there are usually two meters: one that measures the whole electricity usage of the site and another that measures the electricity generated by the solar system. At billing time, the solar electricity is subtracted from the total energy use of the site, and the net value is the amount charged. Thus, the solar electricity provides a credit that is applied against the utility bill (IRENA, 2015).

Further to encourage private generation through solar system, NEA has also formulated a "Feed-In-Tariff" (FIT) policy (GoN, 2017). Generally, this is a payment for each kilowatt-hour of electricity generated by the solar system that is surplus from the site needs. Although, a feed-in tariff can be as high as, or even higher than, the charge for grid electricity, it usually is less (IRENA, 2015). For example, in 2012 in Gujarat, India, when its solar policy was launched, FIT were more than double their grid prices (MNRE, 2016). This was mainly done to initially acceleration of development of solar projects. In Nepal, household and commercial institutions pay electricity price of around Rs.10 and Rs.13 respectively and feed-in tariff is Rs.7.30 (NEA, 2019). Although feed-in tariffs may not be as attractive to the home owners/commercial institutions as net metering, provided the cost of solar generation is lower than the feed-in tariff, the customer is not losing money.

2.1.1. Grid-Tied Solar System Components

A Grid-Tied Solar System mainly has two components (IRENA, 2015):

1. Solar PV Panels that generate electricity when sunlight strikes them.
2. An electronic device called an inverter that converts the direct current (DC) electricity from the solar panels to alternating current (AC) that is synchronized with that of the grid.

Apart from these components, there are other minor components such as switches and fuses that allow each of the two major components to be completely isolated when repairs are needed, and protect the components from damage due to short circuits or lightning.

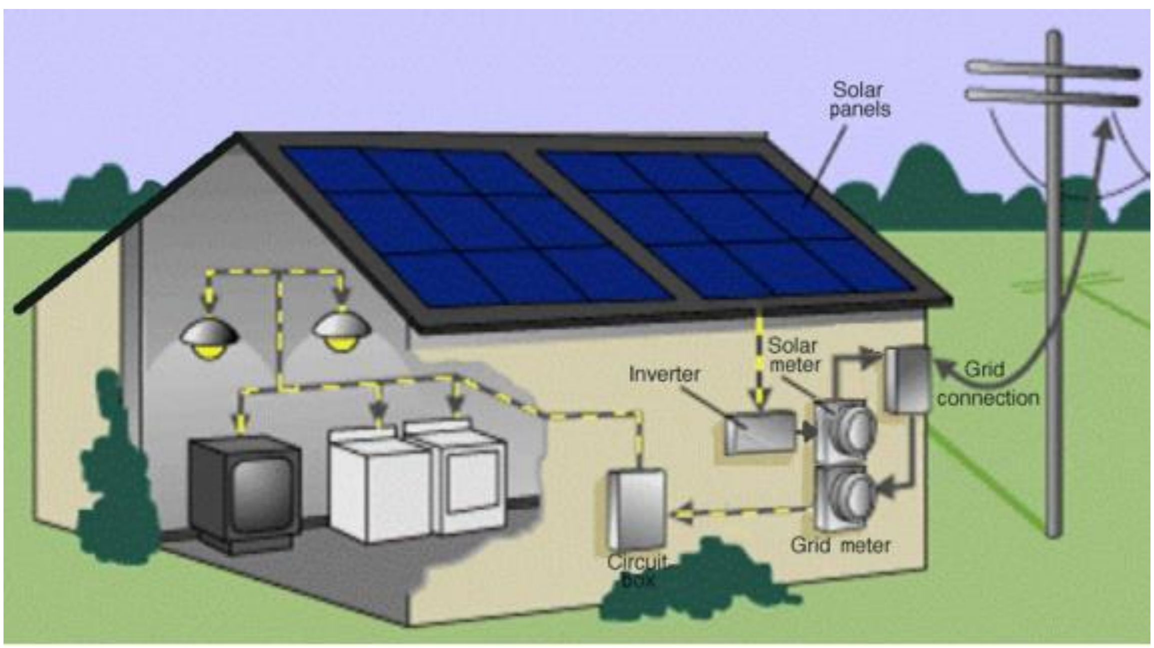

Figure 2-20: A Grid-Tied Solar System (IRENA, 2015)

2.1.2. World Scenario of Grid-Tied Solar System

The capacity of grid-tied solar systems is rising more quickly and continues to account for the vast majority of solar PV installations worldwide, although demand is also expanding for off-grid solar PV systems (Asanuma, 2016). Particularly with the policy/use pattern transition from Feed-in Tariffs (FITs), net metering to self-consumption, decentralized (residential, commercial, industrial rooftop systems) grid-tied applications have faced challenges to maintain a roughly stable global market (in terms of capacity added annually) since 2011 (UN, 2015). Contradictory to this, centralized grid-tied large scale solar PV projects have comprised a significant rising share of annual installations-particularly in emerging markets-despite grid connection challenges, and now represent the majority of annual installation (Figure below) (REN21, 2017). The main drivers for this include increased use of tenders and availability of low cost capital. According to one estimate, an average grid-tied solar project size in early 2016 ranged from 3 MW, 11 MW, 45 MW, 64 MW in Europe, North America, Africa and South America respectively.

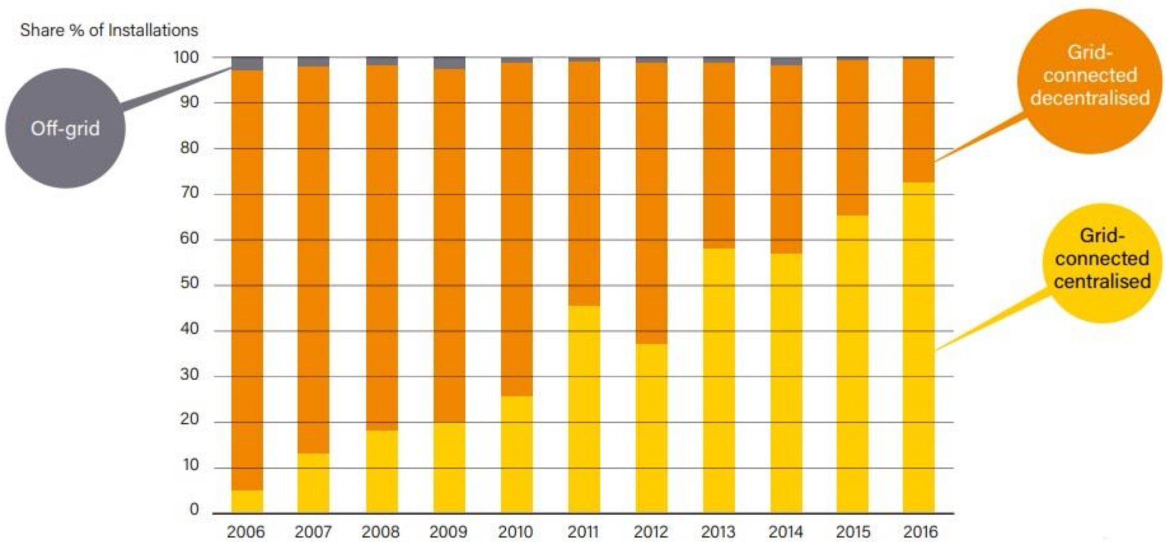

Figure 2-21: Solar PV Global Additions, Shares of Grid-Connected and Off-Grid Installations, 2006-2016 (REN21, 2017)

In 2016, number and size of large scale grid-tied solar PV plants continued to grow around the world. By the end of 2016, at least 164 (up from 124 in 2015) grid-tied solar PV plants of 50 MW and larger were operating in at least more than two dozen nations with Israel, Jordan, the Philippines and the United Kingdom joining the list during the year (REN21, 2017). The combined capacity of plants on 50 MW and larger that came into operation in 2016 was more than 5.9 GW (Sachs, 2016).Among these, China's Yanchi project in Ningxia successfully became the world's largest plant with 1 GW capacity (REN21, 2017).

Domestic and international organizations based in China, Europe, India, North America and elsewhere invested heavily in solar PV during 2016 (Mulkern, 2016). New projects came into operation in Australia, Europe and the United States (IEA, 2016). In Japan, an estimated 45MW of community-owned solar PV came into operation by the end of 2016. Increasingly in Australia and the United States, utilities and other energy companies are developing "community" projects to retain existing customers and attract new ones.

In electricity generation in several countries, solar PV has a substantial share. In 2016, solar PV accounted for 9.8% of net generation in Honduras and met 7.3% of electricity demand in Italy, 7.2% in Greece and 6.4% in Germany. At least 17 countries (including Australia, Chile, Honduras, Israel, Japan and several in Europe) had enough solar PV capacity at end-2016 to meet 2% or more of their electricity demand(REN21, 2017).

2.1.3. Grid-Tied Solar System in India

The Ministry of New and Renewable Energy (MNRE), Government of India has announced an ambitious solar target of 100, 000 megawatts (MW) installed capacity by 2022, of which 40,000 MW of solar photovoltaic (PV) systems are to be installed on rooftops (MNRE, 2016). There have been several efforts at the policy, regulatory and implementation levels for solar rooftop deployment in India, For a long time, the country witnessed solar installations with the help of Government funding, which has now started evolving to various public-private partnership (PPP) and private sector-based models. With dramatic reduction in PV prices over the last couple of years, an era of 'grid-parity' has been reached, where the cost of solar electricity is competitive with retail electricity tariffs in many cases. This presents a whole new opportunity for the country, the sector and the market. However, in order to realize widespread solar rooftop deployment opportunities, the implementation process for each stakeholder needs to be clear and simple.

Name	State	District	Capacity (kWp)
D-Mart			**1415.7**
D Mart(Badlapur)	Maharashtra	Thane	100.8
D Mart(Mulund)	Maharashtra	Mumbai Suburban	320
D Mart(Pratap Nagar)	Rajasthan	Jaipur	39
D Mart(Ajmer)	Rajasthan	Ajmer	70
D Mart(Kondhwa)	Maharashtra	Pune	56.92
D Mart(Daman)	Gujarat	Daman	32
D Mart(Rajkot)	Gujarat	Rajkot	71.82
D Mart(Zirakpur)	Punjab	Sahibzada Ajit Singh Nagar	44.4
D Mart(Bhilwara)	Rajasthan	Bhilwara	112
D Mart(Devanahalli)	Karnataka	Bangalore	161.92
D Mart(Nellore)	Andhra Pradesh	Nellore	99.22
D Mart(Ongole)	Andhra Pradesh	Prakasam	81.9
D Mart(Madhurwada)	Andhra Pradesh	Vishakhapatnam	58.2
D Mart(Tirupati)	Andhra Pradesh	Chittoor	33.075
D Mart(Kanakapura)	Karnataka	Bangalore Urban	134.4
MIT-Pune			**934.8**
MIT Talegaon	Maharashtra	Pune	192.2
MIT Alandi 1	Maharashtra	Pune	209
MIT Talegaon 2	Maharashtra	Pune	308
MIT Alandi 2	Maharashtra	Pune	225.6
Bigbasket			**299.2**
Bigbasket Bangalore	Karnataka	Bangalore	200
Bigbasket Chennai	Tamil Nadu	Tiruvallur	99.2

Figure 2-22: Grid-Tied Solar System in India (FP, 2019)

2.1.4. Grid-Tied Solar System in Nepal

In the context of Nepal, the grid connection of PV power is in the starting phase. Few attempts have been made in this sector which is presented below:

2.1.4.1. Grid-Tied Solar Power Plant at Sundarighat

The plant was installed at the end of June 2012 with the aid of Government of Japan. The solar project, funded by Japan International Cooperation Agency (JICA), aims to demonstrate how renewable energy can add up electric power to the national grid. The project produces 680.4 kW of solar energy under Photovoltaic (PV) generation system at the existing open pond of Dhobighat and connects to water treatment supply facility at Sundarighat. The PV system uses solar panels to convert sunlight into electricity. The electricity generated by the plant is being supplied to the nearby Sundarighat Water Treatment Plant of Kathmandu Upatyaka Khanepani Limited and the surplus energy is transferred to the grid distribution network of Nepal Electricity Authority (KP, 2013).

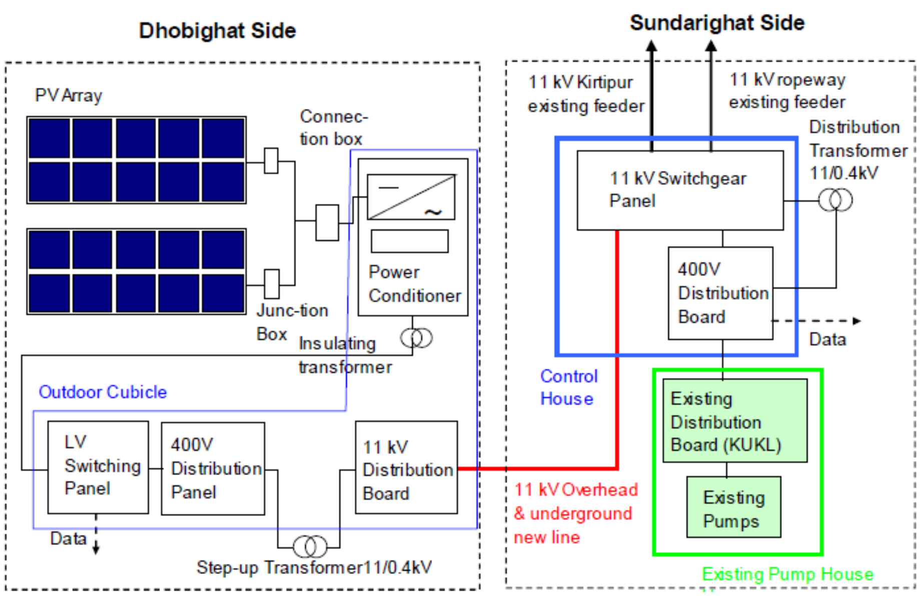

Figure 2-23: System diagram of Grid-Tied Solar Power Plant at Sundarighat (Shakya, 2015)

2.1.4.2. Grid-Tied Solar Power Plant at Kharipati

This 100 kW grid-tied solar power plant is located at Nepal Electricity Authority (NEA) training centre, Kharipati, Bhaktapur District, Nepal (Tiwari, 2017). This project was supported by Asian Development Bank (ADB). This was considered for pilot project for grid connected solar PV electric system.

Figure 2-24: Grid-Tied Solar Power Plant at Kharipati (Tiwari, 2017)

2.1.4.3. Grid-Tied Solar Power Plant at Singha Durbar

The Chinese Government had installed 1 MW grid-tied solar system as grant to Nepal, at a total cost of about Rs.600 million. The solar panels have been installed on the roof of 21 buildings, including all the ministries located within Singha Durbar, Kathmandu (THT, 2019). The installation of solar panels also complements government's recent policy whereby general consumers who install solar power for domestic use can sell surplus power to NEA.

Figure 2-25: Grid-Tied Solar Power Plant at Singha Durbar

2.1.4.4. Grid-Tied Solar Power Plant of SUPSI

Five 1.11 kW solar PV grid-connected systems were installed between October and December 2012 in the Kathmandu valley in different, urban locations (Shrestha et al). At the CES (Centre of Energy Studies), Pulchowk Engineering Campus of Tribhuvan University, a standard grid-connected 1.11 kW PV plant was installed.

Figure 2-26: Grid-Tied Solar Power Plant at CES (Bhattarai, 2013)

At NEA (Nepal Electricity Authority) Min Bhawan office three equal, standard grid-connected 1.11 kW PV systems were installed and connected to the grid.

Figure 2-27: Grid-Tied Solar Power Plant at NEA, Minbhawan (Bhattarai, 2013)

At RIDS Nepal office, Imadol Lalitpur, 1.11 kW solar PV grid-connected system, with a battery bank as back-up system, was installed.

Figure 2-28: Grid-Tied Solar Power Plant at RIDS Nepal (Bhattarai, 2013)

2.2. Global Grid Tied Solar System Research Direction

Several researches have been performed on grid-tied solar systems in Nepal and internationally which are discussed below:

Ayompe et. al. (2011) performed a research on Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland and found final yield and reference yield of the system under study were 2.41 kWh/kW/day and 2.85 kWh/kW/day respectively. This study also determined performance ratio and capacity utilization factors of the system were 0.815 and 10.1% respectively.

Bhattarai (2013) studied the performance analysis of one kilowatt grid connected solar PV system at Center for Energy Studies (CES), Institute of Engineering, Tribhuvan University measuring the real field data and found out average final yield from the system was 2.31 kWh/day, array yield was 2.64 kWh/day and performance ratio of 0.488 under normal loadshedding. His study also determined per unit cost of electricity was NRs. 16.63.

Chokmaviroj et al. (2006) presented the performance of a 500 kWp grid connected photovoltaic system at Mae Hong Son Province, Thailand and found average of generating electricity production per day was 1695.9 kWh. The final yield ranged from 2.91 to 3.98 h/day and the performance ratio was in the range of 0.7 to 0.9.

Table 2.1: Researches on Grid Tied Solar System

S.N.	Country	Capacity (kW)	Reference Yield (Y_R) (kWh/kW/day)	Final Yield (Y_F) (kWh/kW/day)	PR	CUF (%)	Source
1	Ireland	1.72	2.85	2.41	0.815	10.1	Ayompeet et. al., 2011
2	Nepal	1	2.64	2.31	0.49	-	Bhattarai, 2013
3	Thailand	500	-	2.91 to 3.98	0.7 to 0.9	-	Chokmavirok et. al., 2006
4	India	80	-	-	0.838	18.26	Kumar and Nagarajan, 2016
5	India	20	-	-	0.82	17.2	Kumar et. al., 2016
6	Nepal	1000	-	4.81	0.773	20.18	Shrestha, 2014
7	Nepal	100	4.14	2.42	0.34 to 0.7	10.09	Tiwari, 2017
8	India	190	-	-	0.74	9.27	Sharma and Chandel, 2013
9	India	11.2	-	-	0.78	-	Sharma and Goel, 2017
10	South Africa	3.2	-	-	0.84	-	Okello et. al., 2015
11	Brazil	2.2	5.6	4.6	0.829	19.2	Lima et. al., 2017

Kumar and Nagarajan (2016) calculated the performance ratio and the various power losses (power electronic, temperature, soiling, internal, grid availability and interconnection) of 80kWp grid connected roof top Transformer less photovoltaic power plant in Tamilnadu, India. This research showed the system had performance ratio of 0.838 and capacity utilization factor of 18.26%.

Kumar et al. (2014) discussed the study of performance carried out on a roof top 20 kWp solar photovoltaic (PV) power plant in a reputed manufacturing industry in India. This study showed the solar plant had a performance ratio of 0.82 and capacity utilization factor of 17.2%.

Shrestha (2014) performed a research on Techno-Economic Analysis of Utility Scale PV Plant , A Case Study on 1 MWp Plant at Trishuli and found system yield, capacity utilization factor of the plant would be 4.81 kWh/kWp/day, 20.18% and 0.773 respectively. He also determined cost of electricity from the plant would be NRs.10.5/kWh. His final conclusion was utility scale grid tied solar PV plant is technically and economically feasible for meeting the energy deficit in Nepal.

Tiwari (2017) performed a study on Performance Analysis of 100 kWp Grid Connected Solar PV System, A Case Study at Kharipati, Bhaktapur, Nepal and found total yearly measured energy output from the system was 88.40 MWh with maximum during November (10.53 MWh) and minimum in January (4.39 MWh), average final yield for the year 2016 was 2.42 kWh/Wp/ day. This research also determined the network unavailability was one of the hurdles in injecting energy to the grid which degraded the overall performance of the system.

Sharma and Chandel (2013) performed the performance analysis of a 190 kWp grid connected solar photovoltaic power plant in Khatkar-Kalan, India. The result presented an insight to the long term performance of the solar power plant under actual operating conditions in India. The researched found system had a performance ratio of 0.74, capacity factor of 9.27 % and system efficiency of 8.3%.

Sharma and Goel (2017) presented the result of 11.2 kWp roof top grid connected PV system in Eastern India, which was monitored from September 2014 to August 2015. This study found performance ratio of the system was 0.78 and total energy generated during study period was 14.96 MWh.

Okello et.al. (2015) performed a study on analysis of measured and simulated performance data of a 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa and found measured performance ratio of the system under study was 0.84.

Lima et.al. (2017) performed a study on Performance analysis of a grid connected photovoltaic system in northeastern Brazil and found reference and final yield of the system were 5.6 kWh/kW/day and 4.6 kWh/kW/day respectively. This study also found performance ratio and capacity utilization factor of the system were 0.829 and 19.2% respectively.

Apart from these, following researches were also studied.

Bhattarai (2004) performed a study on Grid-Connected PV system in Nepal and found out the main consumers of national grid are urban houses where electricity could be generated by solar photovoltaic technology in individual houses and can be tied to national grid. His study also showed grid connected solar system is financially feasible if subsidy is provided.

Chianese (2014) et al. performed a study on Impact of Small decentralized PV Grid-Connected Plants on Load Shedding in Nepal and found the energy production was as high as expected, comparable to the irradiation level. During the seven month of the analysis period, the irradiation level was 22% lower than NASA meteorological data. This research also determined, a small distributed grid-connected system of up to 50 MW could be installed in a short period in the Kathmandu valley and would help to improve the energy availability in the country.

Pendem and Mikkili (2018) performed a study on Modeling, simulation and performance analysis of solar PV array configurations (Series, Series-Parallel and Honey-Comb) to extract maximum power under Partial Shading Conditions. This research found when the number of PV modules per string and the number of strings shaded in a PV array increases, reduces the maximum power generation capability by causing mismatching power losses.

Rachchh et. al. (2016) performed a study on Solar photovoltaic system design optimization by shading analysis to maximize energy generation from limited urban area. This research found with optimization of tilt angle and by accounting the shadow, 25% more land area could be utilized effectively for the solar PV system installation. This could lead to a loss of about 1% in terms of specific generation (kWh/kW), which is negligible as compared to the increment of installed capacity by more than 25%.

Shakya (2015) performed a case study on Grid Integrated Solar PV for National Dasrath Stadium and determined levelized cost of electricity (LCOE) of utility scale hybrid grid tied solar PV plant would be NRs.18/kWh for 20 years and LCOE of purely grid tied solar PV plant would be NRs.12.5/kWh for 20 years. This research concluded utilizing benefits of grid tied solar PV plant, Nepal's only national stadium could displace use of diesel generators and minimize the day time utility electricity expenses, leading to sustainable operation.

2.3. Technical Performance Parameters of PV System

Accurate and consistent evaluations of solar photovoltaic (PV) system performance are critical for the continuing development of the PV industry. For component manufacturers, performance evaluations are benchmarks of quality for existing products. For research and development teams, they are a key metric for helping to identify future needs. For systems integrators and end customers, they are vital tools for evaluating products and product quality to guide future decision-making.

In order to analyze the performance of Solar PV system, the performance parameters have been developed by International Energy Agency Photovoltaic Power Systems (IEA PVPS) Program and are described in the IEC standard 61724:1998. Photovoltaic systems of different configurations and at different locations can be readily compared by evaluating their normalized system performance parameters such as yields, losses and efficiencies (IEC, 1998). Yields are energy quantities normalized to rated array power. System efficiencies are normalized to array area. Losses are the differences between yields. The PV systems performance parameters of grid-connected, standalone and hybrid systems can differ significantly due to load matching and other unique operating characteristics. These performance parameters or indices include (Marion et al., 2005; Sharma and Chandel, 2013):

1. Total energy generated by the PV system (E_{AC})

2. Reference yield (Y_R)
3. Final yield (Y_F)
4. Performance ratio (PR)
5. Capacity utilization factor (CUF)
6. Overall system efficiency (η_{system})
7. Normalized energy losses (L_T)

2.3.1. Total Energy Generated by the PV System (E_{AC})

The total daily ($E_{AC,d}$) and monthly ($E_{AC,m}$) energy generated by the PV system (Sharma and Chandel, 2013) is given as:

$$E_{(AC,)} = \sum_{t=1}^{24} {}_{(AC,t)} \quad \text{...Equation 2.1}$$

$$E_{(AC,)} = \sum_{d=1}^{N} {}_{(AC,d)} \quad \text{...Equation 2.2}$$

Where, N is the number of days in the month, ($E_{AC,t}$) is the instantaneous measured value of generated energy or energy injected to grid. The instantaneous energy output was obtained by measuring the energy generated by the PV system after the DC/AC inverter. The yearly energy output can be found by summing the monthly generated energy.

2.3.2. Reference Yield (Y_R)

Reference yield is defined as the ratio of total in-plane solar insolation, H_t (kWh/m^2) to the PV reference irradiance, G (1 kW/m^2). This parameter represents equal number of hours at the reference irradiance and is given by:

$$Y_R = H_t\,(kWh/m^2) \,/\, G\,(1\ kW/m^2) \quad \text{hours ...Equation 2.3}$$

Y_R is the number of peak sun-hours and defines the solar radiation resource for the PV system. It is a function of the location, orientation of the PV array, and month-to-month and year-to-year weather variability.

2.3.3. Final Yield (Y_F)

Final yield is defined as 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 and is given by:

$Y_F = E_{AC} / P_{PV,rated}$ kWh/kW or hours …Equation 2.4

It represents the number of hours that the PV array would need to operate at its rated power to provide the same energy. The units are hours or kWh/kW, with the latter preferred by the authors because it describes the quantities used to derive the parameter (Marion et al., 2005). The Y_F normalizes the energy produced with respect to the system size; consequently, it is a convenient way to compare the energy produced by PV systems of differing size.

2.3.4. Performance Ratio (PR)

Performance ratio is defined as the ratio of the final yield (Y_F) to the reference yield (Y_R). This normalizes performance parameter with respect to the incident solar radiation is a dimensionless quantity and provides important information on the overall effect of losses while converting DC to AC. The higher the PR of the system better is the performance of the system as compared to other systems in similar climatic conditions. According to the EU Performance project, a PR of 0.8 and above is an indicator of a good performing system (Khalid et al., 2016). PR is one of the main performance indicator adopted in PV monitoring schemes established by several countries such as the US, Australia, and the European Union. Experiences of a large number of PV plant operators indicate that a continuous monitoring of PR is helpful in correcting system faults. PR values are greater in the winter than in the summer and normally fall within the range of 0.6 to 0.8. If PV module soiling is seasonal, it may also impact differences in PR from summer to winter. Decreasing yearly values may indicate a permanent loss in performance (Marion et al., 2005).

$PR = Y_F / Y_R$ …Equation 2.5

The performance ratio indicates the overall effect of losses on the array's rated output due to array temperature, incomplete utilization of the irradiation, and system component inefficiencies or failures (IEC, 1998). It is a unit-less quantity. This parameter is used to evaluate the long-term changes in the performance and decreasing year wise PR values are indicative of loss in the performance. It represents the fraction of energy actually available after deducting energy losses (Okello et al., 2015).

2.3.5. Capacity Utilization Factor (CUF)

The capacity utilization factor (CUF) is a means used to present the energy delivered by an electric power generating system. If the system delivers full rated power continuously, its CUF would be unity (Ayompe et al., 2011). The capacity utilization factor is defined as the ratio of the actual energy output of the PV system (E_{AC}) to the amount of energy the PV system would generate if it operates at full rated power ($P_{PV\ rated}$) for 24 h per day and is given as:

$CUF = E_{AC,day} / (P_{PV,rated} * 24)$ …Equation 2.6

2.3.6. Overall System Efficiency (η_{system})

The efficiency of a PV system is grouped into PV array efficiency, system efficiency and inverter efficiency. Depending on the available data and desire level of resolution, these efficiencies can be determined on instantaneous, hourly, daily, monthly and yearly bases. The overall system efficiency (η_{system}) is defined as the ratio of the total AC energy output of the system to the total energy collected from the PV field (Carmo de Lima et al., 2015).

$\eta_{system} (\%) = \{E_{AC} / (H_t \times A_{PVarray})\} \times 100$ …Equation 2.7

where, E_{AC} = total energy output by the system (kWh),

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

$A_{PVarray}$ = total area of the PV system.

2.3.7. Normalized Energy Losses (L_T)

Normalized energy losses are calculated by subtracting yields. Losses have units of kWh/day/kW or hour/day and indicate the amount of time during which the array would be required to operate at its rated power Prated to provide for the losses (IEC, 1998).

Energy losses occur at every stage of the system. Some important losses in the PV plant are: array capture losses, thermal losses and system losses. Array capture losses occur due to poor irradiance levels, and thermal losses due to array soiling, module mismatch, partial shading of modules, etc. System losses include power conversion loss in inverter, wiring loss, MPPT tracking loss, etc. Power conditioning units are very often located in a small building some distance away from the generator. According to literature (Ayompe et al., 2011), the wiring losses from the PV panels to the converters are in the vicinity of 3% for most applications. The inverters often have high conversion efficiencies at the rated power input, but for low irradiance levels and low power input the conversion efficiency decreases. Therefore, the average conversion efficiency over a whole day could be considerably lower than the rated one.

Array Capture Losses (L_C)

Array Capture losses are due to PV array operation and are given as (Ayompe et al., 2011):

$L_C = Y_R - Y_A$ …Equation 2.8

System Losses (L_S)

The system losses is due to the conversion of DC into AC by the Power Conditioning Unit and is given by Sharma and Goel (2017).

$L_S = Y_A - Y_F$ …Equation 2.9

The total energy loss (L_T) of the PV power plant is the sum of Array Capture Losses and System Losses. It represents numerically the difference between the reference yield (Y_R) and the final yield (Y_F) (Okello et al., 2015).

$L_T = L_C + L_S$ …Equation 2.10

$L_T = Y_R - Y_F$ …Equation 2.11

Results obtained will provide useful information to policy makers and interested individual and organization about actual performance of grid connected PV system in a region or country (Carmo de Lima et al., 2015).

2.4. Economic Performance Parameters of PV System

The return on investment in solar PV system depends on electricity price and revenue sources. The investment analysis is varied based on the economic parameters which characterize the PV system economic performance. The economic parameters which are considered in order to evaluate a PV system are discussed in the section below.

2.4.1. Monthly Bill Savings (MBS)

The monthly electricity bill savings are used to measure the PV system capacity to reduce the monthly electricity bill for end consumers. This monthly bill saving are normally used by the third party owners to show the PV system cost reduction potential. In this project the following formula is used to calculate the bill savings:

Monthly net savings = cost without PV system – cost with PV system …Equation 2.12

2.4.2. Discounted Payback Period (DPBP)

The total payback time to return the capital investment is known as payback period, and is an important decision-making indicator for the investment. Usually, shorter payback time is good for the investment. Simple payback and discounted payback are two common methods are used to calculate payback time in PV system. Simple payback period is the time required to return the initial investment cost to net revenues without discounted money. Discounted payback period is a method to calculate the payback time of investment with discounted revenues to exceed the discounted costs. This is highly dependent on the investor's economic condition, as a longer payback period has a higher risk of money liquidity. The main limitation of payback period is that; it can't measure the system profitability. This is not an effective economic analysis of a project by taking only payback time into account as a main decision making indicator (Drury, 2011).

In discounted payback period, the present value of each cash inflow has to be calculated. For this purpose the management has to set a suitable discount rate which is usually the company's cost of capital. The discounted cash inflow for each period is then calculated using the formula:

$$Discounted\ Cash\ Inflow = \frac{\text{Actual Cash Flow}}{(1+i)\hat{}n}$$

…Equation 2.13

Where,

i is the discount rate; and

n is the period to which the cash inflow relates.

The rest of the procedure is similar to the calculation of simple payback period except that the discounted cash flows has to be used as calculated above instead of nominal cash flows. Also, the cumulative cash flow is replaced by cumulative discounted cash flow.

$$Discounted\ Pay\ back\ period\ (DPBP) = \text{A} + \frac{\text{B}}{C}$$

…Equation 2.14

Where,

A = Last period with a negative discounted cumulative cash flow;

B = Absolute value of discounted cumulative cash flow at the end of the period A; and

C = Discounted cash flow during the period after A.

2.4.3. Net Present Value (NPV)

The Net present value (NPV) is the key economic parameter to evaluate the system investment. It measures the investment profit by calculating the present value of future money by taking the discount rate into account. NPV is calculated by summing up all the cash outflows and inflows of the investment for an analysis period. The cash flow for each year is discounted with a discount rate. The outflows are calculated as negative values and inflows are considered as positive. The resulting value defines the project net present value. Positive NPV denotes a profitable investment and negative NPV shows the opposite. The following formula is used to determine the NPV (Chun, 2013):

$$NPV = -C_0 + \sum_{0}^{N} (C/(1+d)\hat{}N)$$

…Equation 2.15

Where,

C is the total cash flow in the analysis period after tax,

C_0 is the capital investment, d is the nominal discount rate and

N is the project analysis period

2.4.4. Internal Rate of Return (IRR)

Internal rate of return (IRR) is the discount rate at which the net present value of an investment is zero. IRR is one of the most popular capital budgeting technique. Companies invest in different projects to generate value and increase their shareholders wealth, which is possible only if the projects they invest in generate a return higher than the minimum rate of return required by the providers of capital (i.e. shareholders and debt holders). The minimum required rate of return is called the hurdle rate. IRR (Internal Rate of Return) is a discounted cash flow (DCF) technique which means that it incorporates the time value of money. The initial outlay/investment in any project must be compensated by net cash flows which far exceed the initial investment. The higher those cash flows when compared to the initial outlay, the higher will be the IRR (Internal Rate of Return) and the project is a promising investment.

IRR is most commonly calculated using the hit-and-trial method, linear-interpolation formula or spreadsheets and financial calculators. Since IRR is defined as the discount rate at which NPV = 0, it can be written that:

NPV = 0; or

PV of future cash flows − Initial Investment = 0; or

$$\left(\frac{\mathrm{CF1}}{(1+r)^1}+\frac{\mathrm{CF2}}{(1+r)^2}+\frac{\mathrm{CF3}}{(1+r)^3}+\cdots\right)-Initial\ Investment=0$$

…Equation 2.16

Where, r is the internal rate of return;

CF1 is the period one net cash inflow;

CF2 is the period two net cash inflow,

CF3 is the period three net cash inflow, and so on ...

2.4.5. Levelized Cost of Energy (LCOE)

The Levelized cost of energy (LCOE) is measured from the expected lifetime cost (development, financing, fuel, maintenance, operation, incentives and taxes) and annual energy production. All the cost and benefits are calculated considering inflation and discounted factor to estimate the actual time value of money. This is a valuable metric to compare different generation options to choose the lowest cost of energy production. Although, the initial cost of renewable energy based generation is high, but it is compensated by zero fuel cost and low operating cost in comparison with others at the system life time. In a conventional plant, the LCOE cost depends on the fuel cost and maintenance cost which changes during project times for several factors. LCOE cost for renewable energy is more accurate to predict with lower cost. The main limitation of LCOE is that, it fails to measure the future capacity expansion cost and revenue of the project. In recent years, the cost of module and balance of the system is reduced significantly which drops down the LCOE for PV systems. The global utility-scale average LCOE of solar PV declined by 58% in 2015. It varies from countries weather profile, global market trends and economic metrics. The following two formulas are commonly used to calculate the LCOE with nominal and real discount rate (Drury, 2011).

$$LCOE = \frac{\text{Sum of cost over lifetime}}{Sum\ of\ electricity\ produced\ over\ lifetime}$$

$$LCOE = \frac{\sum_{t=1}^{n}(It + Mt + Ft)/(1+r)\char`^2}{\sum_{t=1}^{n} Et/(1+r)\char`^2}$$

…Equation 2.18

Where,

I_t: investment expenditures in the year t

M_t: operation and maintenance expenditures in the year t

F_t: fuel expenditure in the year t

E_t: electricity generation in the year t

r: discount rate

n: expected lifetime of system or power station

3. CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Research Method

The research began from the problem identification, literature review, the concepts of Grid tied PV systems and PV system types, study of international standards, earlier work on Grid Tied Solar Plant in the country and abroad, data collection and compilation of the installed grid-tied solar system. Further, technical and economic performance analysis of the 64.6 kWp grid tied solar system at Nepal Telecom, Sundhara, Kathmandu was performed. Fig. below presents a research methodology flowchart followed for this thesis.

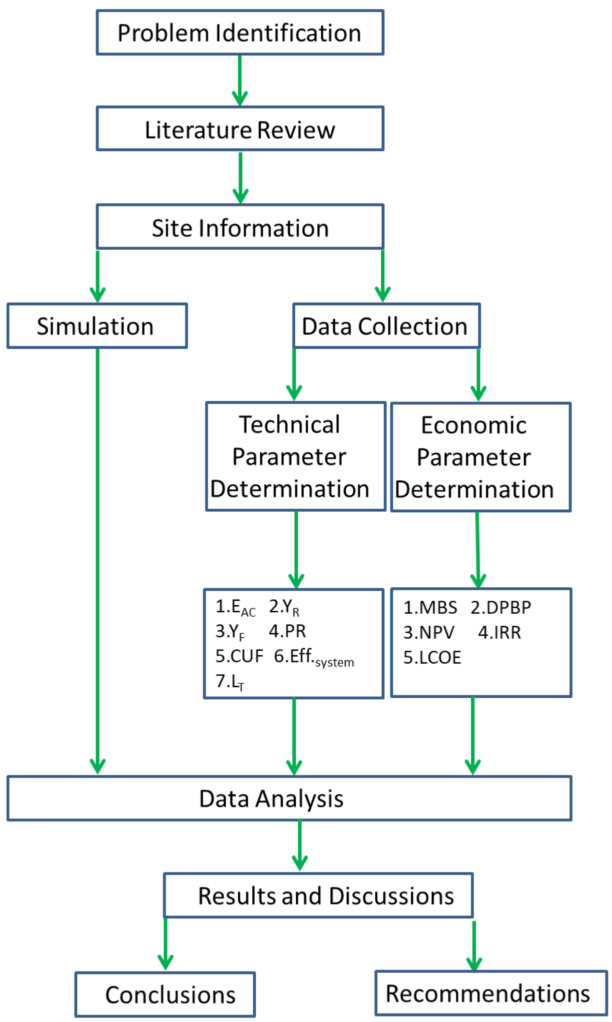

Figure 3-1: Research Methodology Flowchart

3.1.1. Data Sources and Collection

Data collection was performed with practical observations through frequent site visits and through the data logger installed at the site. For the performance analysis of the grid tied PV system, IEC 61724:1998 Standard has been followed which requires using real time data of many parameters. These data include:

1. Solar irradiance in the plane of the array (W/m^2)
2. Ambient Temperature
3. PV array voltage
4. PV array current
5. Power output of PV array
6. Tilt Angle
7. Total Energy Generated by the PV system (E_{AC})

Most of these data were obtained from the site through measurements and through data logger. With request to Nepal Telecom, Sundhara, Kathmandu, the daily data were collected.

3.1.2. Data Analysis and Interpretation

The primary datas were collected from the site, which were five minutes interval based data. The grid tied PV plant was fully monitored to assess its performance as per IEC 61724 standard. This standard was used to find daily and monthly performance parameters. Also the system was built in the simulation software PVsyst and the data generated from simulation process was compared with the actual measured data.

In order to analyze the performance of a grid tied PV system, the performance parameters are being developed by International Energy Agency (IEA) Photovoltaic Power Systems Program. These performance parameters described in the IEC 61724 standard include and used in this research were:

1. Total energy generated by the PV system (E_{AC})
2. Reference yield (Y_R)

3. Final yield (Y_F)
4. Performance ratio (PR)
5. Capacity utilization factor (CUF)
6. Overall system efficiency (η_{system})
7. Normalized energy losses (L_T)

3.1.3. Research tool

Software PVsyst 6.8.5 was used for simulation of 64.6 kWp grid tied solar system at Nepal Telecom, Sundhara, Kathmandu. Further, softwares SketchUP and PVsyst were used for solar system shading analysis. Finally, MS Excel was used for economic performance analysis.

3.2 System Description

3.2.1. Location of site

This research work has been carried out at Nepal Telecom office, Sundhara, Kathmandu. The geographical location of the site was at latitude of 27.70° North and longitude of 85.31° East, Kathmandu district of Bagmati zone in Nepal.

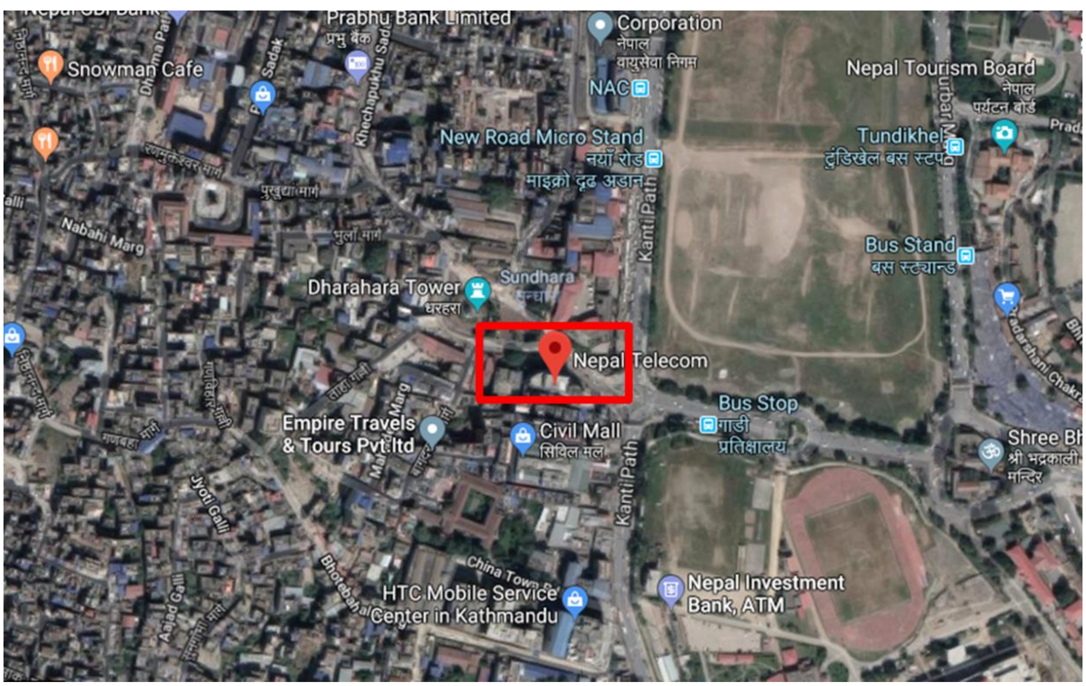

Figure 3-2: Location of the system installed

3.2.2. Space for the system

For solar panel installation, four roofs, three in new building and one in old building (as shows in the figure below) were specified. Dimensions of the roofs are provided in the drawings in ANNEX.

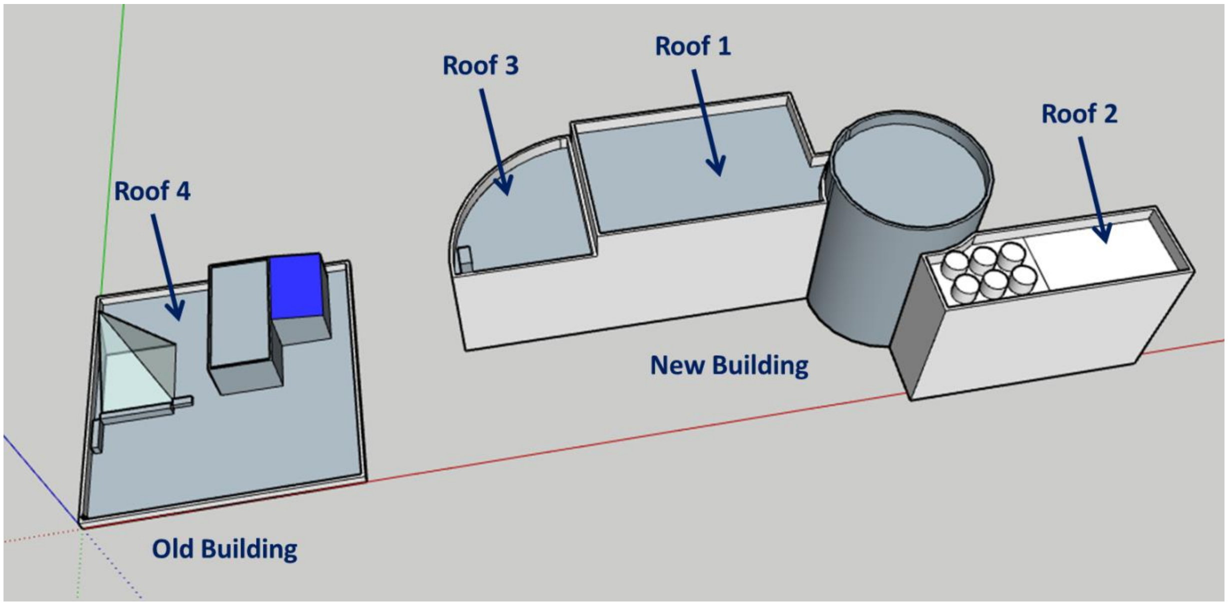

Figure 3-3: Space for the system

3.2.3. Main components of the system

The system consists of the 10 strings of solar panels; each string consists of 19 solar panels in series, one 80 kW grid-tied inverter, protection and measuring devices. It also consists of the data logger and the database system capturing the data.

Table 3.1: Main components and information about the solar system

S.N.	Title	Value
A	Solar Panel(Wp)	340
a.	Total no. of panels	190
b.	Total no. of strings	10
c.	Total no. panels in each strings	19
B	Grid Tied Inverter(kW)	80
a	No. of inverter	1

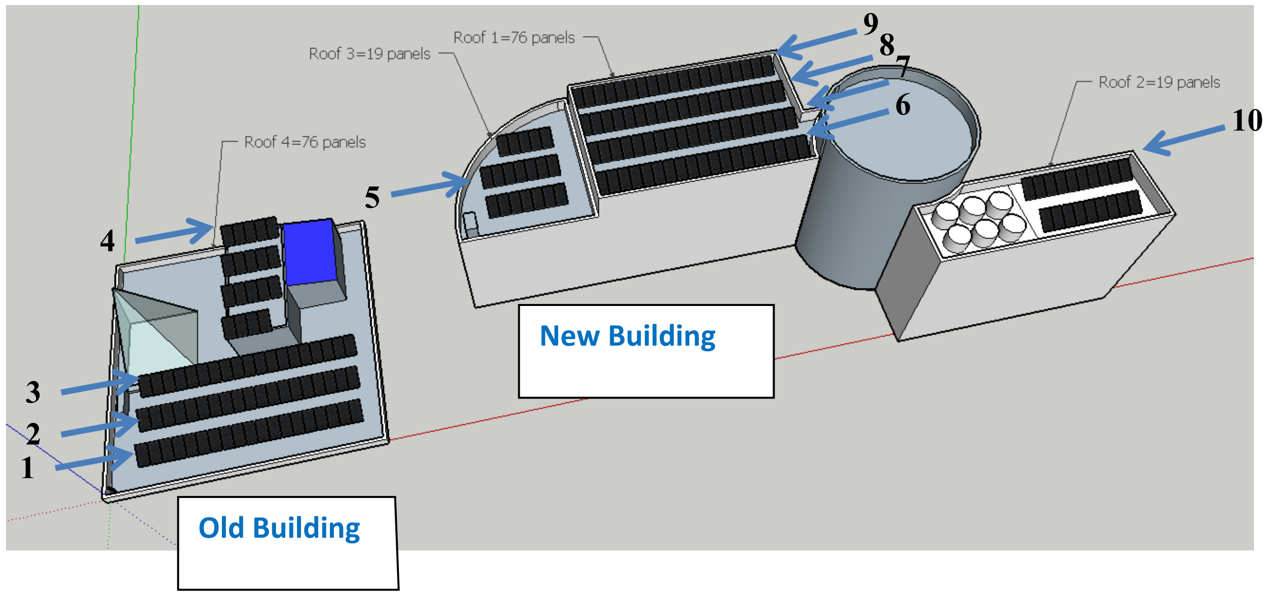

Figure 3-4: System setup with string numbers

Details of solar panel and inverter installed are as follows:

3.2.3.1. Solar panel

Module Specification: The solar panel used in the system was Vikram Solar 340 Wp. It composed of monocrystalline solar cells. Each panel has 72 (6 by 12) cells and module dimensions were 1956 × 992 × 36mm. The I-V curve of the module at Standard Test Condition (STC) with total irradiance of 1000 W/m^2 and cell temperature of 25 °C was shown in Figure below. Also, the electrical specifications of the module were presented in Table below.

Table 3.1: Electrical specifications of solar panel

Electrical Parameter	Values
Peak Power Pmax (Wp)	340
Panel Type	Mono
Maximum Voltage Vmpp (V)	37.98
Maximum Current Impp (A)	8.98
Open Circuit Voltage Voc (V)	47.10
Short Circuit Current Isc (A)	9.42
Module Efficiency η (%)	17.52

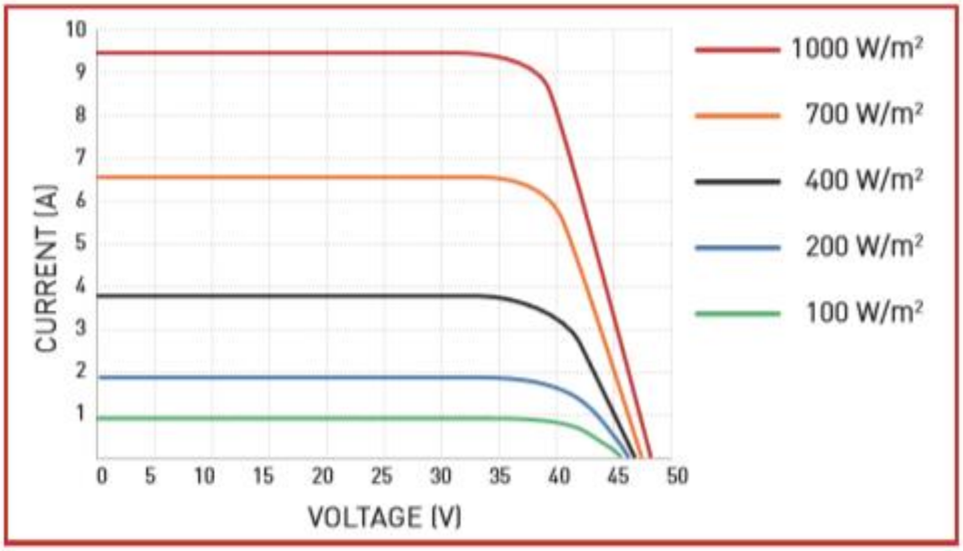

Figure 3-5: I-V Curve of Solar Panel

3.2.3.2. Inverter

Inverter Specification: In this section the employed inverter and its specifications were presented. A 80kW Delta grid-tied solar inverter has been used for all solar array. The technical data of the inverter was shown in Table below.

Table 3.2: Technical data of inverter

Technical Data	Values
Rated Output Power (kW)	80
Max. Input Voltage (V)	1100
DC Voltage Range (V)	200-1000
Nominal DC Voltage (V)	710
Max. Input Current per MPPT (A)	70
Total Input Current (A)	140
No. of Independent MPPT	2

3.2.4. Solar System Installation

Figure 3-6: Roof 1-Solar Panel Installation

Figure 3-7: Roof 2-Solar Panel Installation

Figure 3-8: Roof 3-Solar Panel Installation

Figure 3-9: Roof 4-Solar Panel Installation

Figure 3-10: Inverter Installation

3.2.5. Block diagram of the system

A block diagram of grid-tied solar system has been shown in figure below:

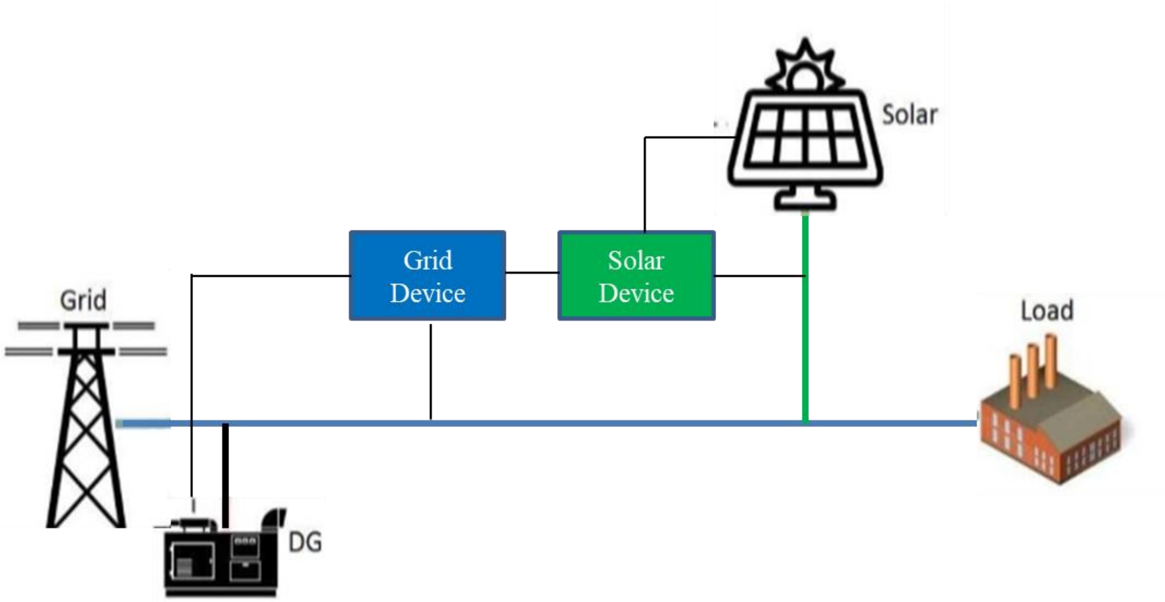

Figure 3-11: Block diagram of the system

The 64.6 kWp grid tied solar system was integrated with utility grid line from Nepal Electricity Authority (NEA) and 1250 kVA diesel generator set. Solar electricity would be first priority for load operation followed by grid line. At the time of power cut, diesel generator would automatically come into operation, and would act as a grid line for solar system operation.

3.3. Simulation of the solar system in PVsyst Software

The solar system under evaluation was simulated in the PVsyst version 6.8.5 software where there was a provision of selecting actual products used at the site i.e.Vikram Solar module of 340W and grid-tied Delta inverter of 80kW. The simulation results were shown below:

Grid-Connected System: Main results

Project : **NTC Sundhara_01**
Simulation variant : **New simulation variant_02**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Shadings of thin objects		Electrical effect	100 %
	Shadings of thin objects		Electrical effect	40 %
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	Somera VSM.72.340.03.04	Pnom	340 Wp
PV Array	Nb. of modules	190	Pnom total	**64.6 kWp**
Inverter	Model	Solar Inverter M80H (480 VAC)		80.0 kW ac
User's needs	Unlimited load (grid)			
Main simulation results				
System Production	**Produced Energy**	**96.05 MWh/year**	Specific prod.	1487 kWh/kWp/year
	Performance Ratio PR	69.45 %		

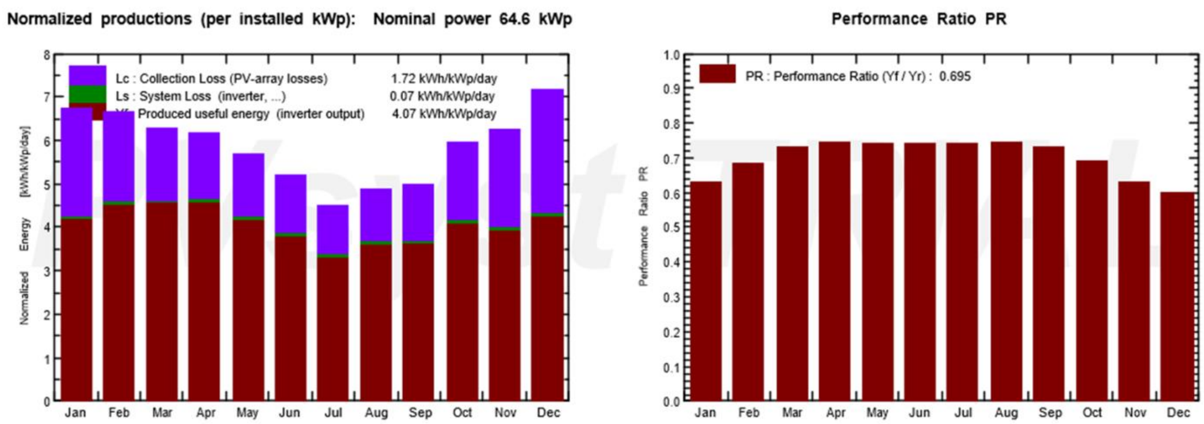

Figure 3-12: Simulation results

Simulation showed the total energy production from 64.6 kWp grid-tied solar system at Nepal Telecom, Sundhara, Kathmandu, would be 96.05 MWh/year, final yield (produced useful energy) of 4.07 kWh/kW/day, specific prod. of 1487 kWh/kW/year and performance ratio of 69.45 % .

Simulation also showed highest generation would be during months of March (9.16 MWh) and April (8.89 MWh). During winter season, highest generating months would be December (8.57 MWh) and January (8.43 MWh). Similarly, lowest generation would be in July (6.70 MWh) and September (7.05 MWh).

4. CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1. Technical Performance Analysis of 64.6 kWp Grid Tied Solar System

This 64.6 kWp grid tied solar system at Nepal Telecom, Sundhara, Kathmandu came into operation from March, 2019. This study was conducted from March to October of year 2019 in order to determine various technical and economic performance parameters of the 64.6 kWp grid tied solar system installed at Nepal Telecom, Sundhara, Kathmandu. The results of the study were discussed in this section.

4.1.1. Maximum Power Generation

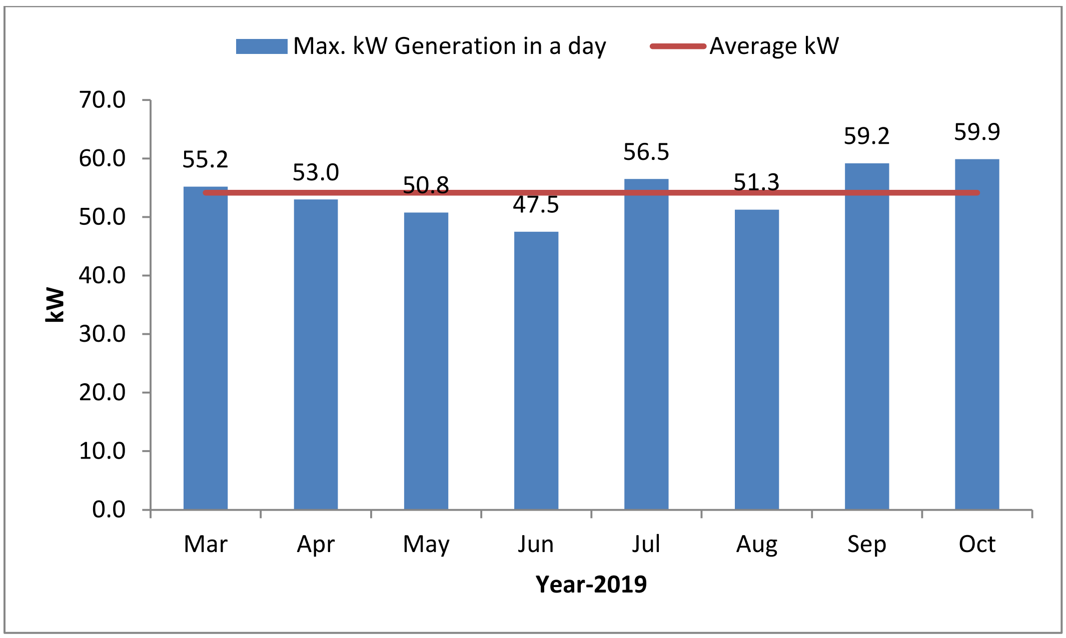

Figure 4-1: Max. Generation (kW) in a day

Fig. above shows maximum power generation (kW) from the power plant in a day during study period from March to October, regarded as the summer season in Nepal. It could be observed, highest power generation in a day was 59.9 kW in October. This generation refers to 92.7% of the total capacity of the system. The lowest value of this parameter falls in the month of June, that was 47.5 kW representing 73.5% of the total capacity of the system. On average, during the study period, highest power generation in a day was found to be 54.2 kW, i.e.83.7% of the total system capacity.

Table 4.1: Max. Generation Info

Month	Day	Time	Max. Generation(kW)	% of (Total Capacity=64.6 kWp)
March	21	12.05	55.2	85.4
April	2	12:20	53.0	82.0
May	5	11:15	50.8	78.6
June	8	11:55	47.5	73.5
July	2	12:00	56.5	87.5
August	27	13:15	51.3	79.4
September	20	13:10	59.2	91.6
October	1	12:00	59.9	92.7

4.1.2. Total energy generated by the PV system (E_{AC})

4.1.2.1. Daily Generation (E_{AC}/day)

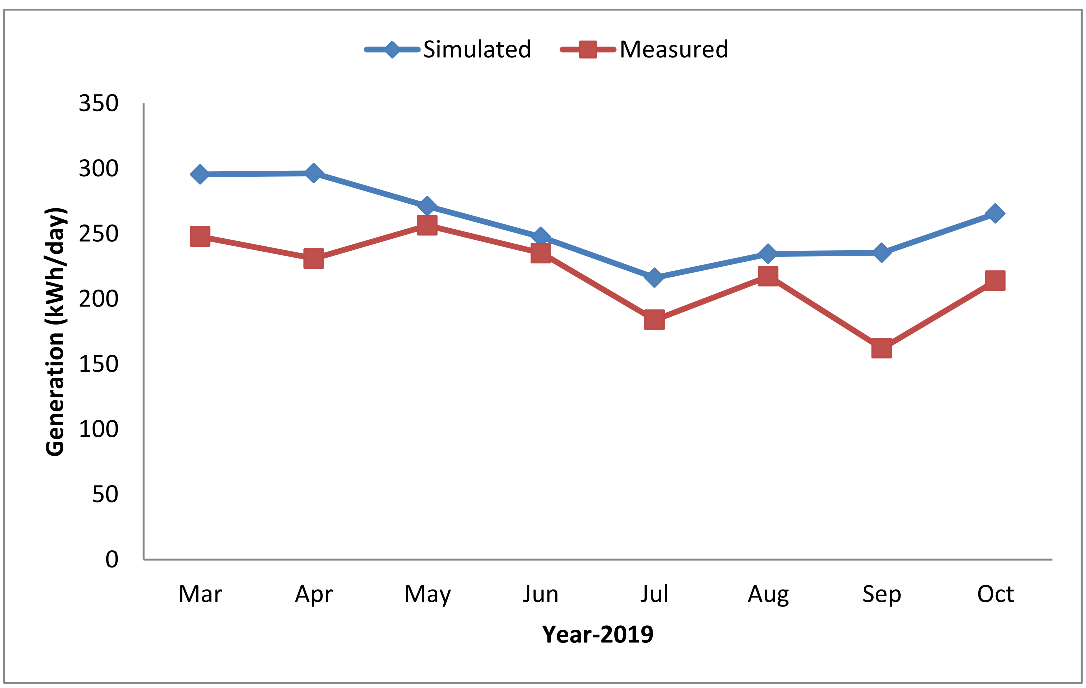

Figure 4-2: Daily Generation

Above plot shows simulated average daily generation varied from 216 kWh (July) to 296 kWh (April). As study period was from March to October, simulated values of the same time were considered for direct comparison with measured values. Plot shows measured average daily generation varied from 162 kWh (September) to 256 kWh (May). In both simulated and measured plot, from March to May, generation was high and from May, plot took a downward path. It could be explained from the fact; months from March to May are the hottest time in Nepal, thereby receiving highest solar radiation and higher generations. However, from mid-June to mid-August, it is monsoon season in Nepal; hence solar panel receives less solar radiation. After mid-August, monsoon concludes in Nepal and sunny days begin again. This was justified by energy generation increment after July in simulated trend. However plot shows, measured generation plot shows downward path from August to September. This was mainly because monsoon is usually supposed to be over by around mid-August, however, this year's monsoon was different as compared to previous years. This year monsoon continued till end of September, hence less solar radiation and thereby less generation. Simulated and measured average daily generations during the study period were found to be 257 kWh and 219 kWh respectively. This showed simulated generation was relatively higher (14.65%) as compared to measured values. Simulated generation values in this case has been obtained with reference to solar radiation from NASA-SEE satellite data in PVsyst software. The working manual of the software states there could be differences in satellite data and ground measured data (PVsyst, 2019). Further, a research performed at Centre for Energy Studies (CES), Institute of Engineering (IOE), Tribhuvan University (TU), showed NASA satellite data was 22% higher than measured solar radiation (Chianese et.al., 2014). Another research also at CES showed, solar irradiance from NASA satellite data was relatively higher (20%) than ground measured values (Tiwari, 2017).

4.1.2.2. Monthly Generation (E_{AC}/monthly)

This grid-tied solar system came into operation from March, 2019. Generation data for the months from March to October were retrieved from Wattmon remote monitoring device and values were presented in the graph along with simulated values from PV syst. Above plot shows, during the eight months of operation, measured generation by the solar system was 53.51 MWh. Measured monthly generation ranged from 4.86 MWh (September) to 7.95 MWh (May). Average measured monthly generation, during study period (March to October), was found to be 6.69 MWh. Similarly simulated highest generation was in March i.e. 9.16 MWh, lowest in July i.e. 6.70 MWh, average simulated monthly generation (March to October) was 7.89 MWh.

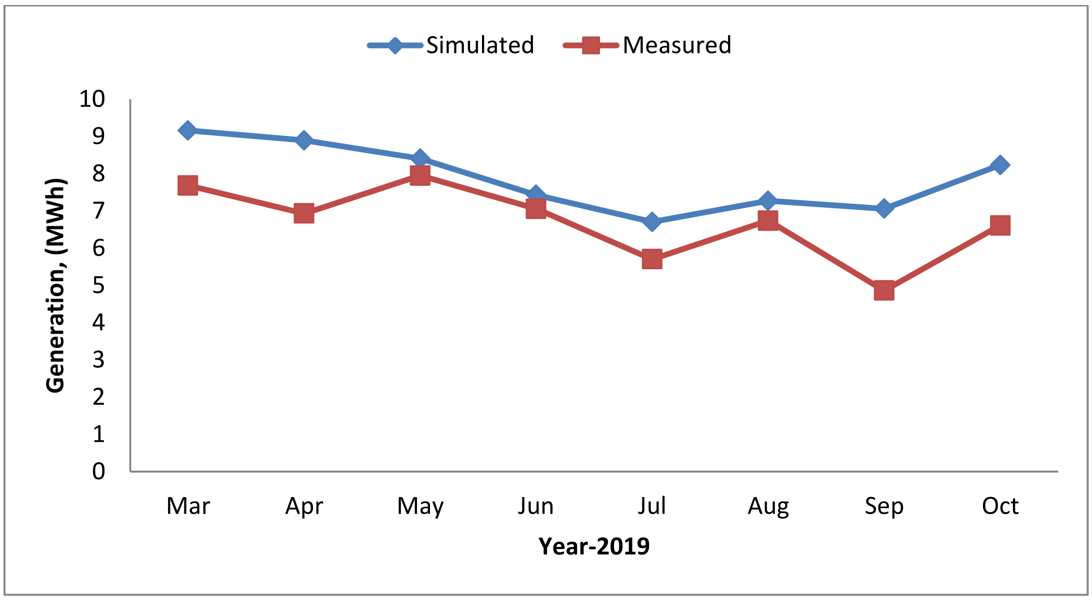

Figure 4-3: Monthly Generation

4.1.3. Reference Yield (Y_R)

At Nepal Telecom, Sundhara, Kathmandu site, during the study period from March to October in 2019, measured daily reference yield varied from 2.93 kWh/kW/day (September) to 4.65 kWh/kW/day (May) while simulated daily reference yield varied from 3.82 kWh/kW/day (July) to 5.43 kWh/kW/day (April). Reference yield refers to solar insolation on the plane of solar panels. March, April and May are hot and sunny months in Nepal; hence it showed highest reference yield months in simulated and measured categories respectively. Similarly, in simulated, July received lowest solar insolation because July is one of the monsoon months in Nepal, thereby receives less solar insolation. However, in measured case, September had lowest reference yield because this year, monsoon continues till the end of September and this month turned out to be month receiving lowest solar insolation among the study period month. Average measured daily reference yield during the study period was 3.94 kWh/kW/day while average simulated daily reference yield during same period was 4.66 kWh/kW/day.

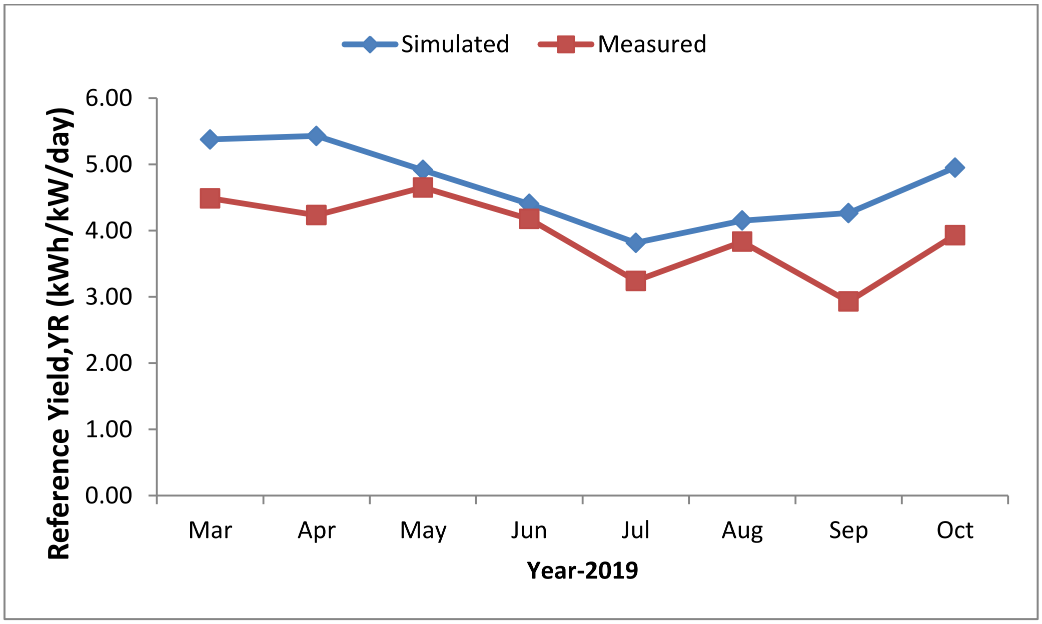

Figure 4-4: Simulated and Measured Reference Yield

4.1.4. Final Yield (Y_F)

Referring to plot below, it was found the measured daily final yield varied from 2.51 kWh/kW/day (September) to 3.96 kWh/kW/day (May). This was because September received lowest solar insolation on the solar panels (2.93 kWh/m^2/day) while May received highest solar insolation on solar panels (4.65 kWh/m^2/ day). March to May is hotter months in Nepal. While low generations during June to August could be explained by - these months are monsoon season in Nepal. September showed lowest final yield which was different from regular pattern. This could be explained from the fact September this year was different from previous years as monsoon season is generally supposed to end by mid-August but this year it continued till the end of September. Average measured daily final yield during the study period was found to be 3.38 kWh/kW/day. Simulated daily final yield was maximum in April, i.e. 4.59 kWh/kW/day while minimum was in July, i.e.3.35 kWh/kW/day. This was because simulation showed

April received highest solar insolation on the solar panels (5.43 kWh/m^2/day) while July received lowest solar insolation on solar panels (3.82 kWh/m^2/ day). Average simulated daily final yield was 3.99 kWh/kW/day.

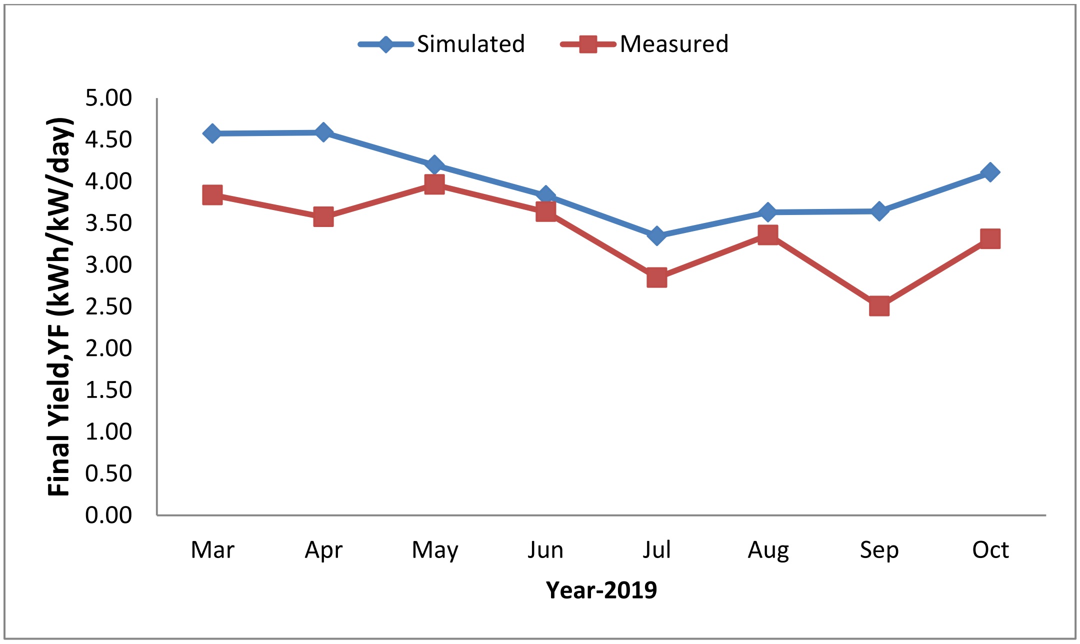

Figure 4-5: Simulated and Measured Final Yield

4.1.5. Performance Ratio (PR)

Graph below shows the measured performance ratio (PR) of the 64.6 kWp grid tied solar system installed at Nepal Telecom, Sundhara, Kathmandu varied in the range of 0.842 (October) to 0.879 (July). Similarly, highest simulated performance ratio was observed in July (0.879) while lowest simulated performance ratio was observed in October (0.830). During the study period from March to October, average performance ratios for measured and simulated data were 0.859 and 0.857 respectively. This shows grid tied solar system could perform better under reduced solar insolation as well.

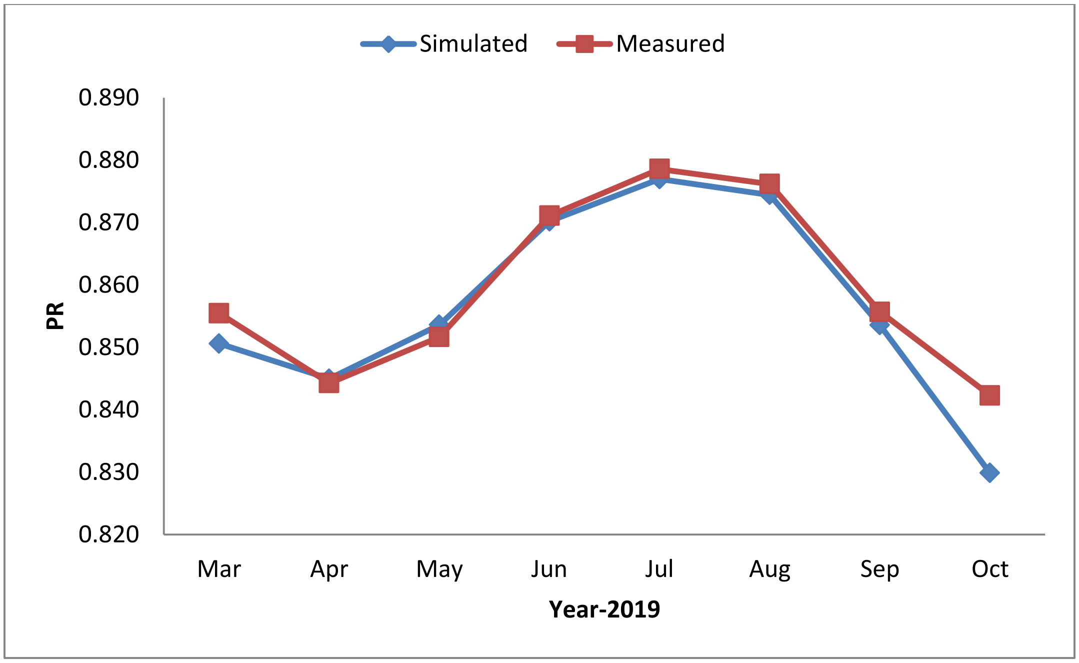

Figure 4-6: Simulated and Measured Performance Ratio

4.1.6. Capacity Utilization Factor (CUF)

Fig. below shows measured capacity utilization factor (CUF) of the solar system under study varied from 10.45% (September) to 16.51% (May). This was mainly because energy generation (162 kWh/day) in September was lowest due to minimum solar insolation (2.93 kWh/kW/day) on solar panels while energy generation (256 kWh/day) in May was highest due to maximum solar insolation (4.65 kWh/kW/day) on solar panels. Similarly simulated capacity utilization factor (CUF) of the solar system under study varied from 13.94% (July) to 19.12% (April). This was mainly because energy generation (216 kWh/day) in July was lowest due to minimum solar insolation (3.82 kWh/kW/day) on solar panels while energy generation (296 kWh/day) in April was highest due to maximum solar insolation (5.43 kWh/kW/day) on solar panels. During the study period, average measured and simulated CUF were found to be 14.09% and 16.62% respectively.

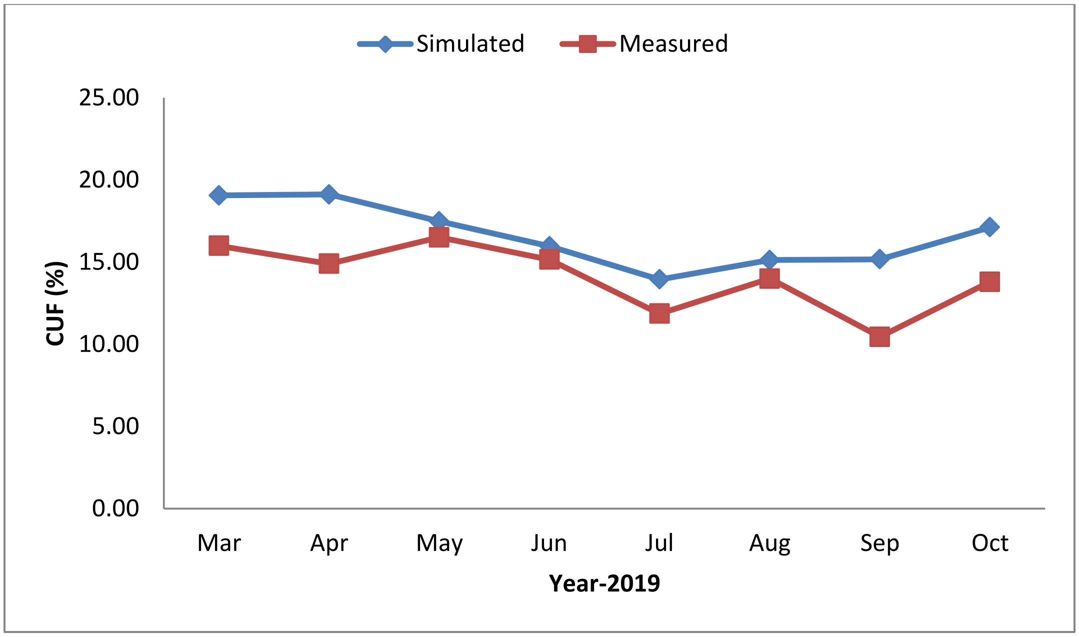

Figure 4-7: Simulated and Measured Capacity Utilization Factor

4.1.7. Overall System Efficiency (η_{system})

Fig. below shows measured overall system efficiency of 64.6 kWp grid tied solar system at Nepal Telecom, Sundhara, Kathmandu varied from 14.76% (October) to 15.39 % (July). Similarly simulated overall system efficiency varied from 14.54% (October) to 15.37% (July). During the study period from March to October, average measured and simulated overall system efficiency were found to be 15.06% and 15.02% respectively. This shows overall system efficiency of grid tied solar system is less affected by higher and lower solar insolation.

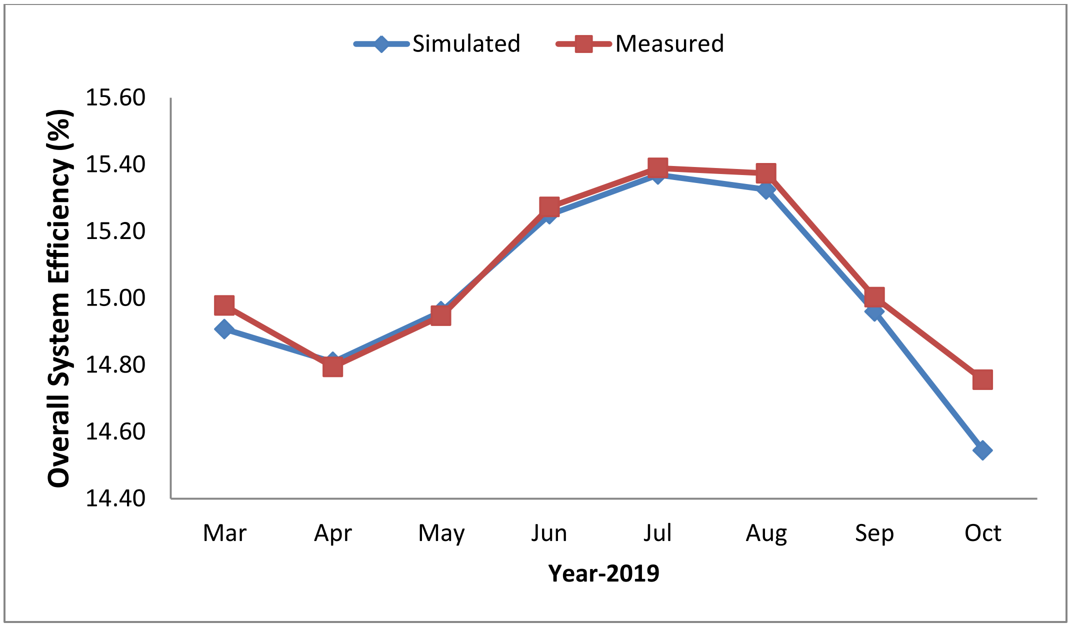

Figure 4-8: Simulated and Measured Overall System Efficiency

4.1.8. Normalized Energy Losses (L_T)

Graph below shows measured total energy loss from the system varied from 0.39 kWh/kW/day (July) to 0.69 kWh/kW/day (May). This could be explained as July had one of the lowest final yield (2.85 kWh/kW/day) and also reference yield (3.24 kWh/kW/day) while May had the highest final yield (3.96 kWh/kW/day) and also reference yield (4.65 kWh/kW/day). Similarly, simulated total energy loss varied from 0.47 kWh/kW/day (July) to 0.84 kWh/kW/day (April). This also could be explained as July had lowest final yield (3.35 kWh/kW/day) and also reference yield (3.82 kWh/kW/day) while April had highest final yield (4.59 kWh/kW/day) and also reference yield (5.43 kWh/kW/day). This shows higher solar insolation results in higher energy generation but at the same time higher losses and lower solar insolation results in lower energy generation but lower losses as well.

On average, during the study period, measured and simulated total energy loss was found to be 0.56 kWh/kW/day and 0.67 kWh/kW/day respectively.

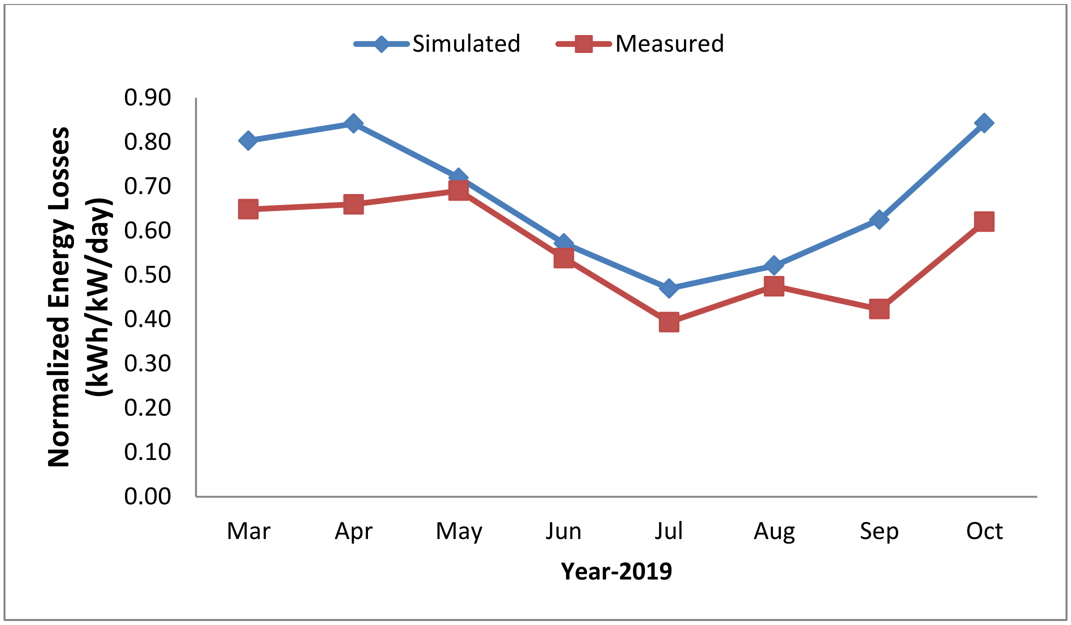

Figure 4-9: Simulated and Measured Normalized Energy Losses

4.1.9. Summary of technical performance parameters

Summary of technical parameters during study period from March to October were presented below:

Table 4.2: Summary of technical performance parameters

S.N.	Technical Parameters	Simulated	Measured
1	Total energy generated by the PV system (E_{AC}/day)	257	219
2	Reference yield (Y_R) (kWh/kW/day)	4.66	3.94
3	Final yield (Y_F) (kWh/kW/day)	3.99	3.38
4	Performance Ratio (PR)	0.857	0.859
5	Capacity Utilization Factor (CUF) (%)	16.62	14.09
6	Overall System Efficiency (η_{system}) (%)	15.02	15.06
7	Normalized Energy Losses (L_T) (kWh/kW/day)	0.67	0.56

4.1.10. Shading Analysis

In order to understand total energy loss in this 64.6 kWp grid tied solar system, a shading analysis would be needed as there are some strings in the system under study which were at considerable shading zones. For this, sketchUP software was used to have an idea of the extent of the shading and after that, analysis of simulation with no shading and shading was performed in PV syst in order to quantify shading losses.

Shading analysis of roofs with panels was performed for all four roofs during summer and winter season. Findings of the analysis have been presented below.

4.1.10.1. Summer Morning (at 9:00 am)

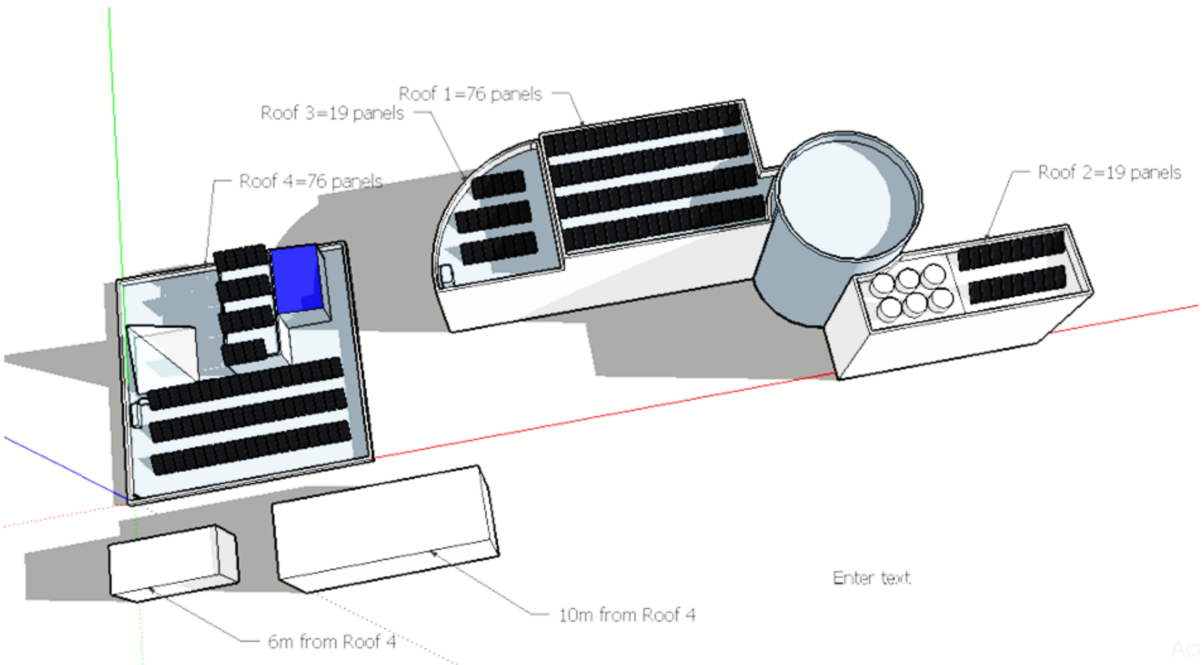

Figure 4-10: Shading Simulation during Summer Morning (10 March at 9:00 AM)

Roof 1: As shown in figure above, in the summer morning, shadow of circular tower part was clearly falling on the panels of two strings in the front. It did not cover a big part. Also, shadow of walls connected to this circular part was also falling to some extent. Roof 2: This space was almost free from shadow area during this time of the day. Roof 3: This space has considerable amount of shadow during morning times because of side walls of Roof 1. Output from this string would be impacted by considerable margin during this time of the day. Roof 4: This space was relatively free from shadows during morning times in the summer. Shadows from right walls are visible; however it was not touching panel areas.

4.1.10.2. Summer Noon (at 12:00)

This is the best time of the day when the solar system is expected to deliver maximum output. Figure below clearly shows all the roofs receiving good sun without any shadows/blockages. Hence this time of the day from the month of March to October, this system is supposed to deliver optimum output from the technology.

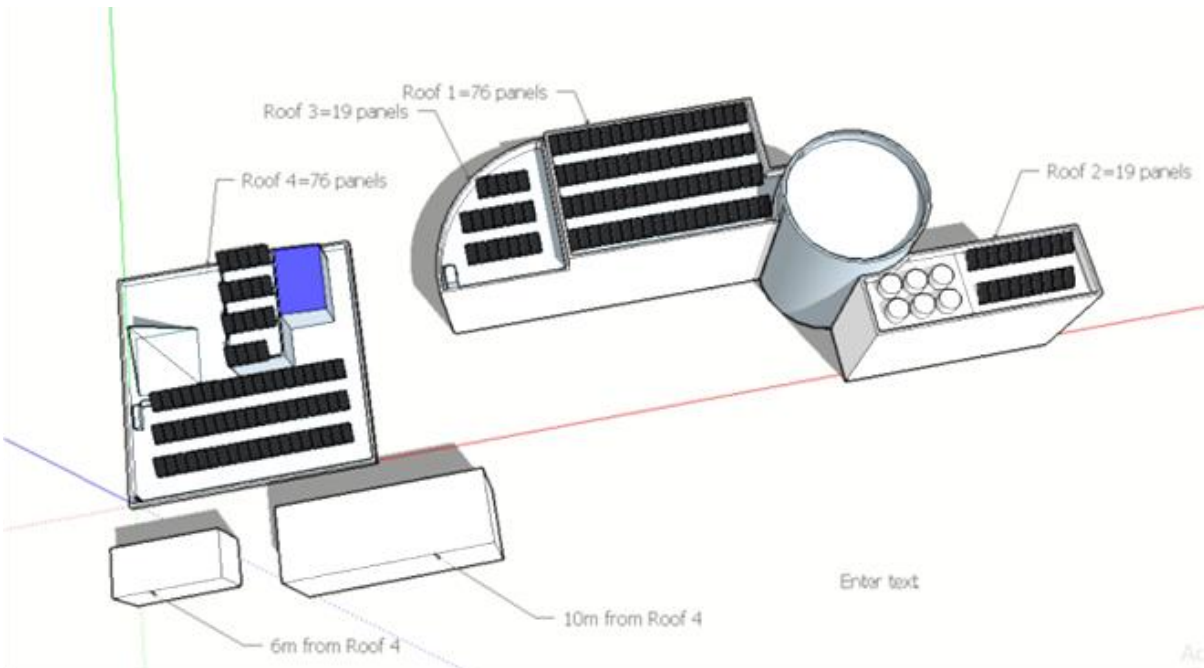

Figure 4-11: Shading Simulation during Summer Noon (10 March at 12:00 Noon)

4.1.10.3. Summer Afternoon (at 3:00 pm)

Roof 1: During this hour of the day also, majority of roof space was receiving sunlight. However, shadow from the left walls of the roof was falling on the panels. Roof 2: This space was almost free from shadow area during this time of the day. Roof 3: Major portion of this roof was free from shadows and receiving good sunlight. Side wall and chimney shadows are showing up during this time of the day. Roof 4: This space was relatively free from shadows apart from shadows from tower.

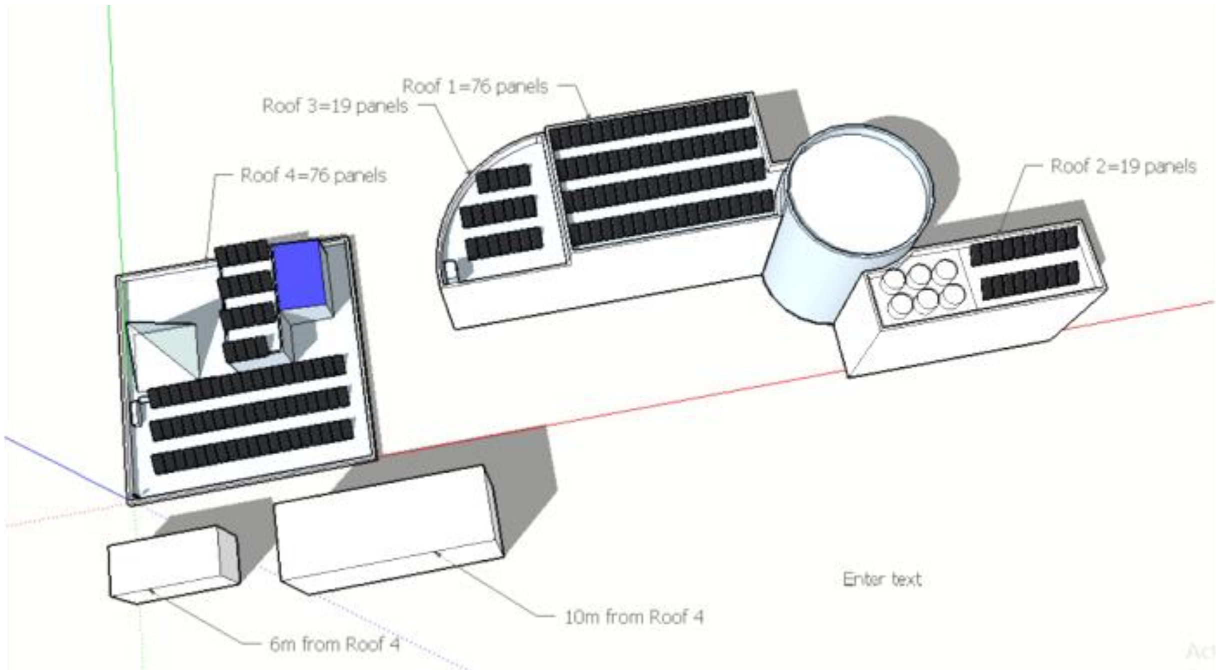

Figure 4-12: Shading Simulation during Summer Afternoon (10 March at 15:00 PM)

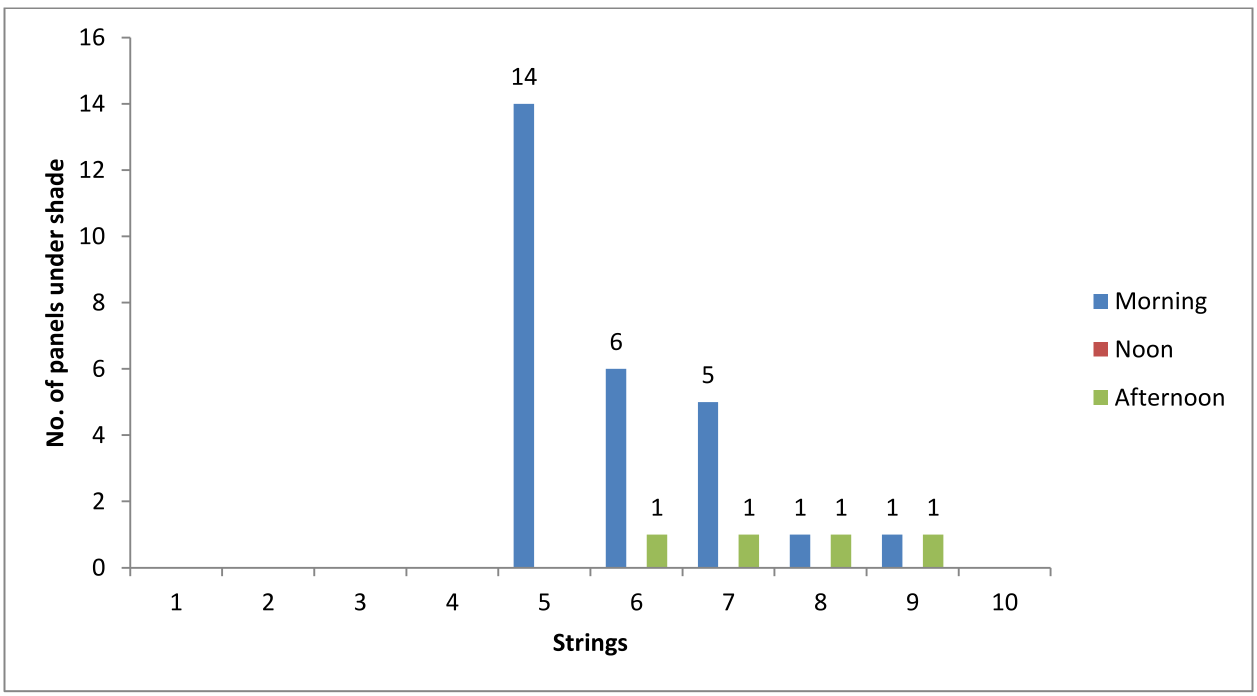

Figure 4-13: No. of panels under shade in summer (Mar-Oct)

Above chart shows number of panels under shade in all strings (1-10) during summer (March-October) morning, noon and after noon times. From this, during mornings, in string 5, 6 and 7, numbers of panels under shade were 14, 6 and 5 respectively. However, as the day progresses, corresponding number of panels in these strings come out of the shade. Most of the other panels in different strings were out of the shade during noon and afternoon during this period of the year. Hence, during eight months in summer, this system should deliver its maximum output.

4.1.10.4. Winter Morning (at 9:00 am)

Roof 1: During this hour of the day, shadows of circular portion were occupying more shadow space as compared to the summer. Apart from this, shadow from the front walls of the roof was falling on the panel space. Roof 2: This space is almost free from shadow area during this time of the day. Roof 3: Shadows of considerable amount has fallen on this space because of front walls and side walls of Roof 1. Hence, output from the string in this space would be impacted during this time of the day. Roof 4: Majority of this space under the shadows because of buildings in front of the space. This shadow part will have three strings (out of 10 strings), hence 30% output of the total system will be impacted.

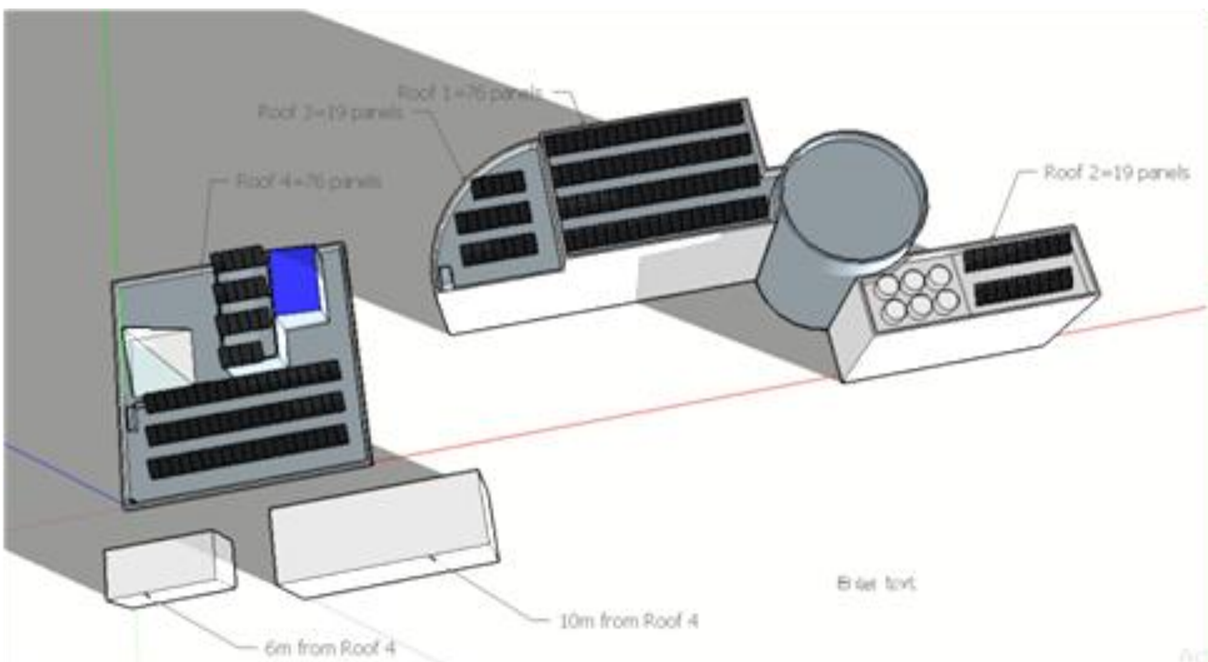

Figure 4-14: Shading Simulation during Winter Mornings (10 January, 9:00 AM)

4.1.10.5. Winter Noon (at 12:00)

Roof 1: During this hour of the day, space was relatively free from any shadow. Roof 2: This space was almost free from shadow area during this time of the day. Roof 3: Shadows of some amount has fallen on this space because of front walls and sideby walls. But overall, majority area was free from shadows. Roof 4: Majority of this space was still under the shadows because of building in front of the space. Hence, strings in this space would have limited output even during noon of the winter.

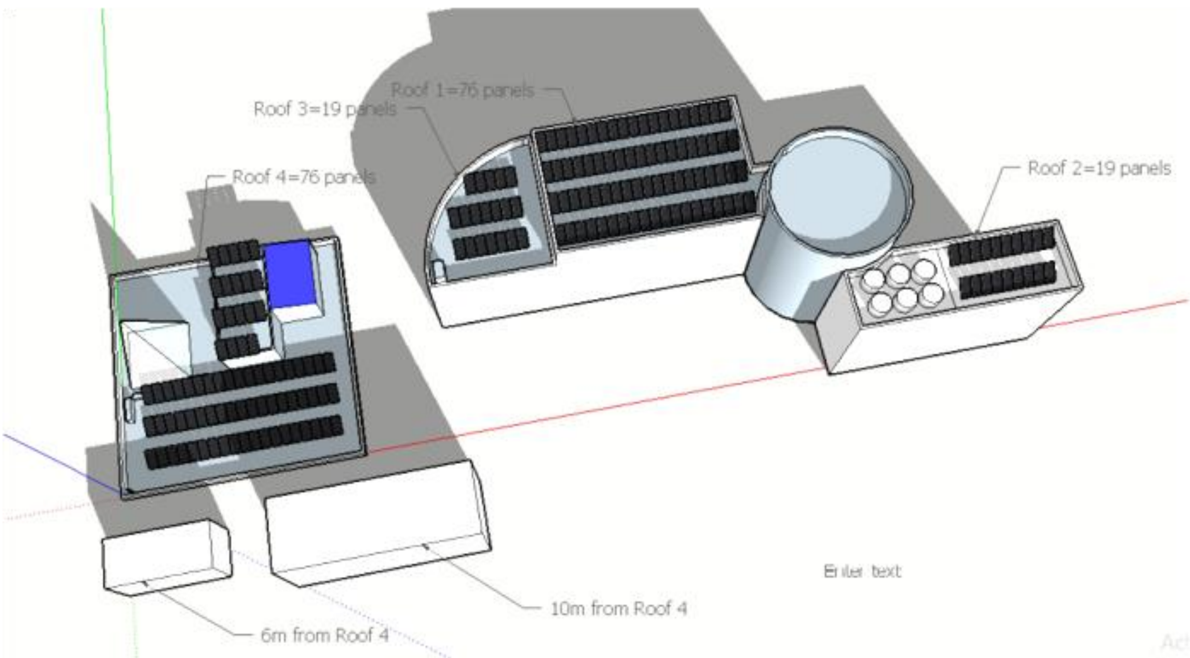

Figure 4-15: Shading Simulation during Winter Noon (10 January, 12:00 Noon)

4.1.10.6. Winter Afternoon (at 3:00 pm)

Roof 1: During this hour of the day, space was relatively occupied with shadows because of front and left side walls. Roof 2: This space was experiencing some shadows because of sideby water tanks and front walls. Roof 3: Shadows of some amount has fallen on this space because of front walls, sideby chimney and circular walls. Roof 4: Majority of this space was under the shadows because of building in front of the space. Hence, strings in this space would have limited output during afternoon of the winter.

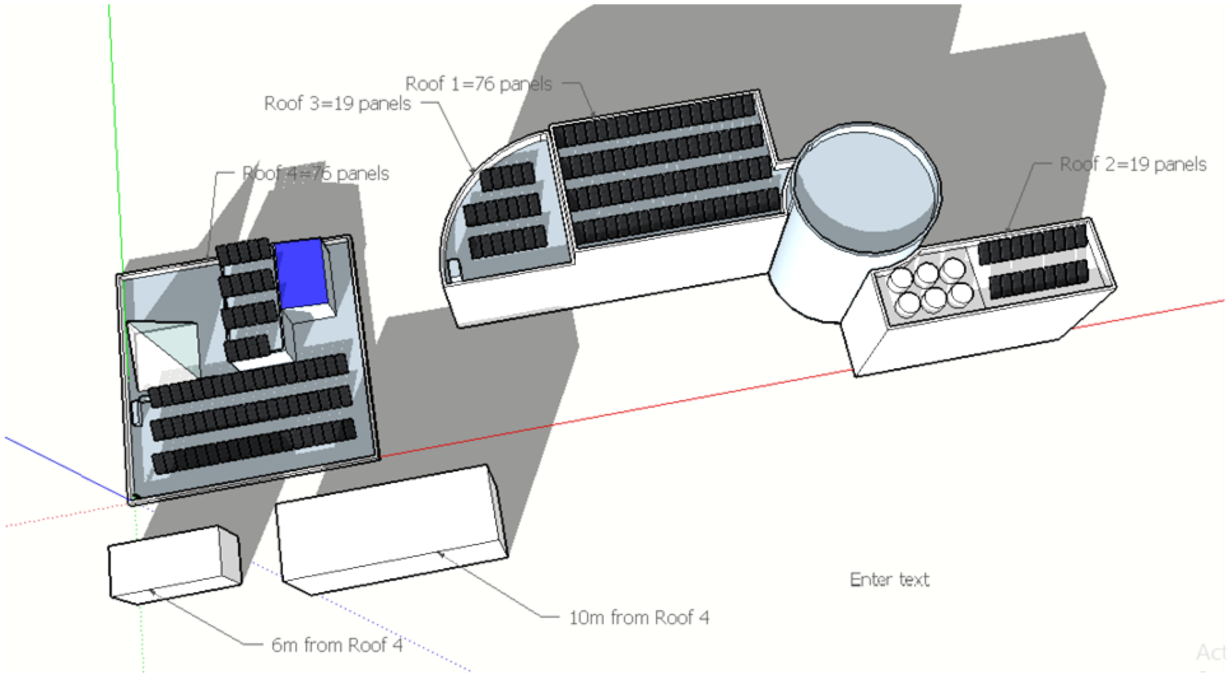

Figure 4-16: Shading Simulation during Winter Afternoon (10 January, 15:00 PM)

Chart below shows number of panels under shade in all strings (1-10) during winter (November-February) morning, noon and after noon times. From this, during mornings, in string 1, 2 and 3 , numbers of panels under shade are about 17 each. This is mainly due to the surrounding buildings. It has to be observed these panels are under shade even during noon and afternoon times. These three strings occupy 30% of the system.

Also about one third of the panels in the strings 5, 6, 7, 8 and 9 were under shade. This is mainly due to the wall and circular structure of its own building. However, as the day progresses, corresponding number of panels in these strings would come out of the shade. Most of the other panels in different strings would be out of the shade during noon and afternoon during this period of the year.

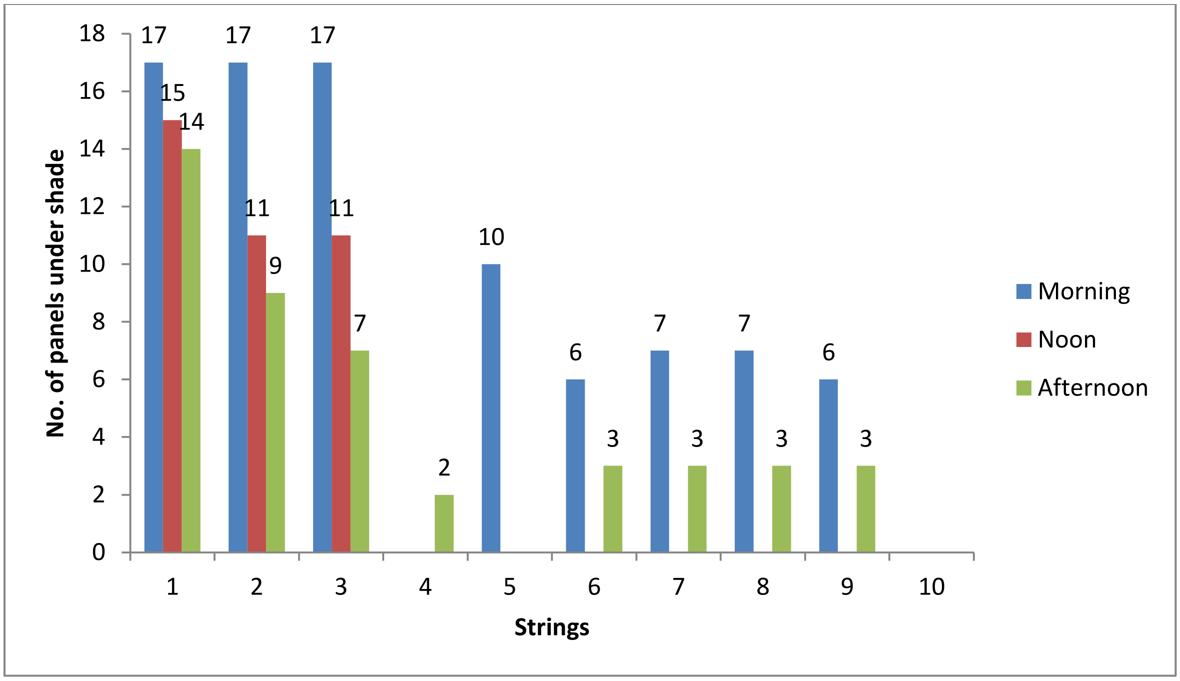

Figure 4-17:No. of panels under shade in winter (Nov-Feb)

This analysis showed how many panels will be under shade during summer and winter mornings, noons and afternoons. In order to quantify shading effect, entire set up of the site was developed in PV syst and simulation performed and results were presented, analyzed and discussed below.

4.1.10.7. Shading simulation in PV syst

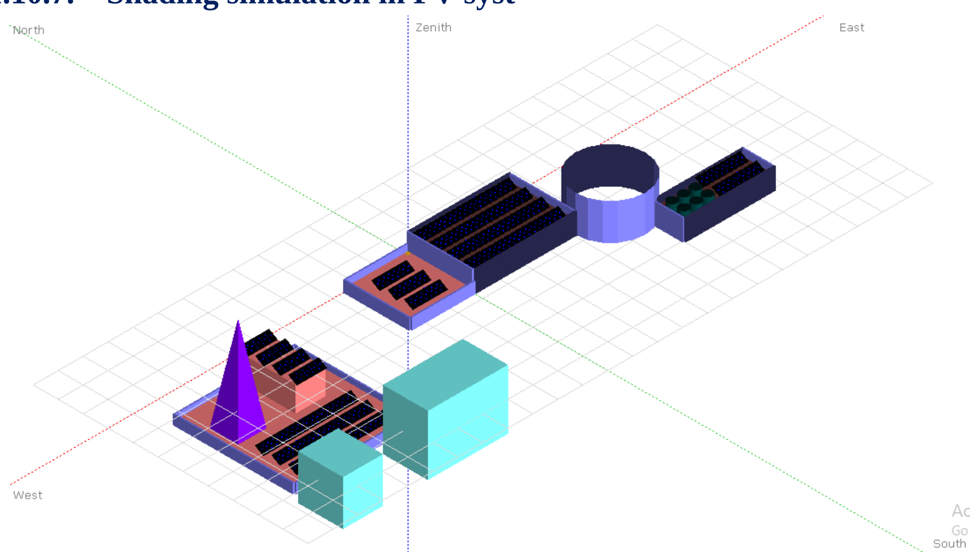

Figure 4-18: Shading Simulation set up in PV syst

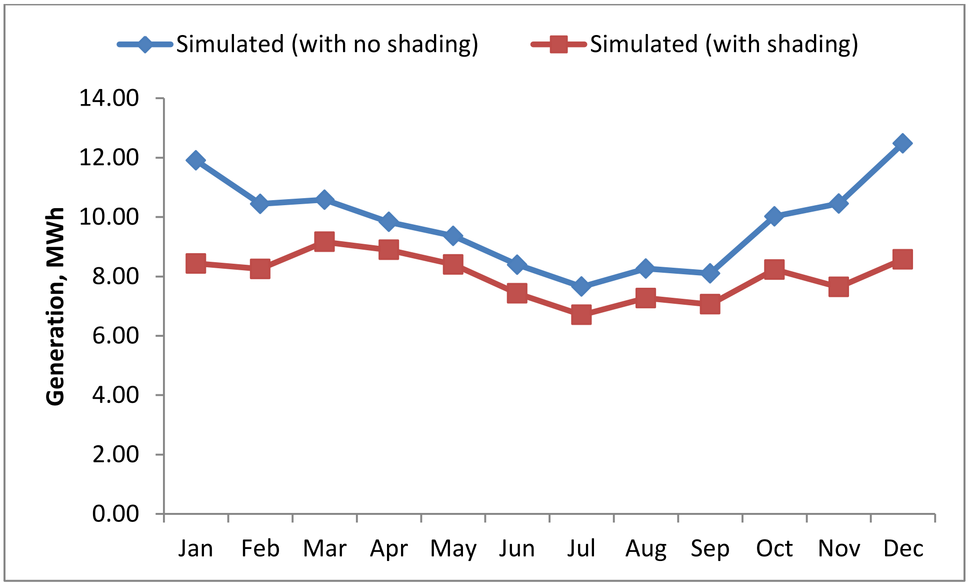

Figure 4-19: Monthly Generation for Simulated (with no shading) and Simulated (with shading)

Above plot shows annual generation from 64.6 kWp grid tied solar system with no shading condition would generate 117.5 MWh of electricity while with shading condition would generate 96 MWh of electricity, causing overall loss of 21.5 MWh (18.3 %) in a year. From the plot above and below, it could be observed during summer, from March to October, shading loss is relatively lesser as compared to during winter, from November to February. From March to October, generation (with no shading) was found to be 72.19 MWh while generation (with shading) during the same period was found to be 63.14 MWh. This showed during summer, there would be shading loss of 12.47 %. Similarly, from November to February, generation (with no shading) was found to be 45.27 MWh while generation (with shading) during same period was found to be 32.90 MWh. This showed during winter, there would be shading loss of 27.06 %. Fig. below illustrates shading loss percentage in detail in every month. Losses were comparatively at a higher range during November to February than from March to October. On average, monthly energy loss due to shading was found to be 17.34 %. The conclusion of this shading analysis would be, due to the shading at the site, there would be monthly energy loss of 1.78 MWh. At NRs.18.50/ kWh electricity price being charged at the site, this refers to amount/revenue loss of NRs.32, 930 per month.

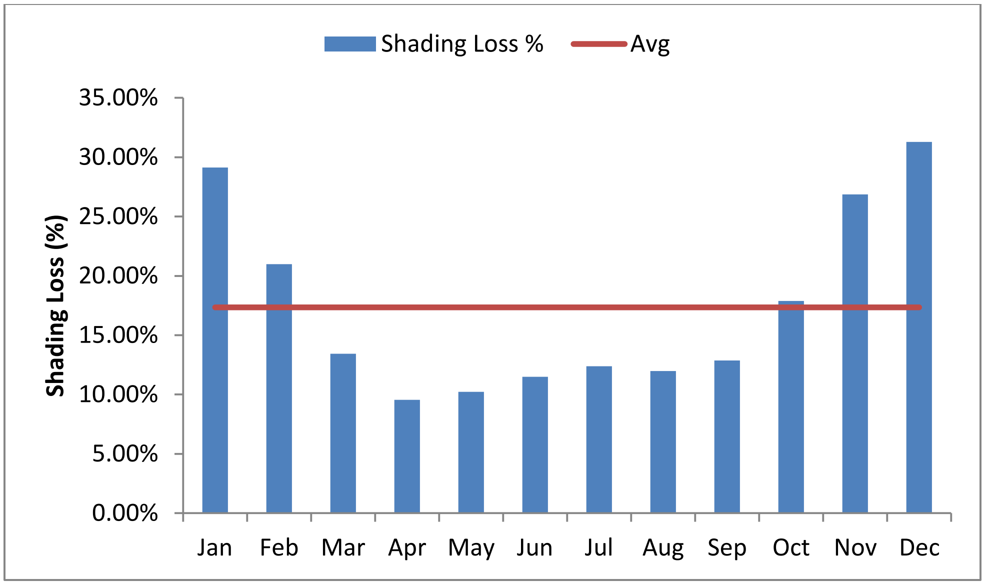

Figure 4-20: Shading Loss

4.2.Economic Performance Analysis of 64.6 kWp Grid Tied Solar System

Total investment of this 64.6 kWp grid tied solar system at Nepal Telecom, Sundhara, Kathmandu was Rs.7,500,000.00. Majority of the cost were for solar panels (55%) and inverter (17%). Cost breakdown of the system were presented below:

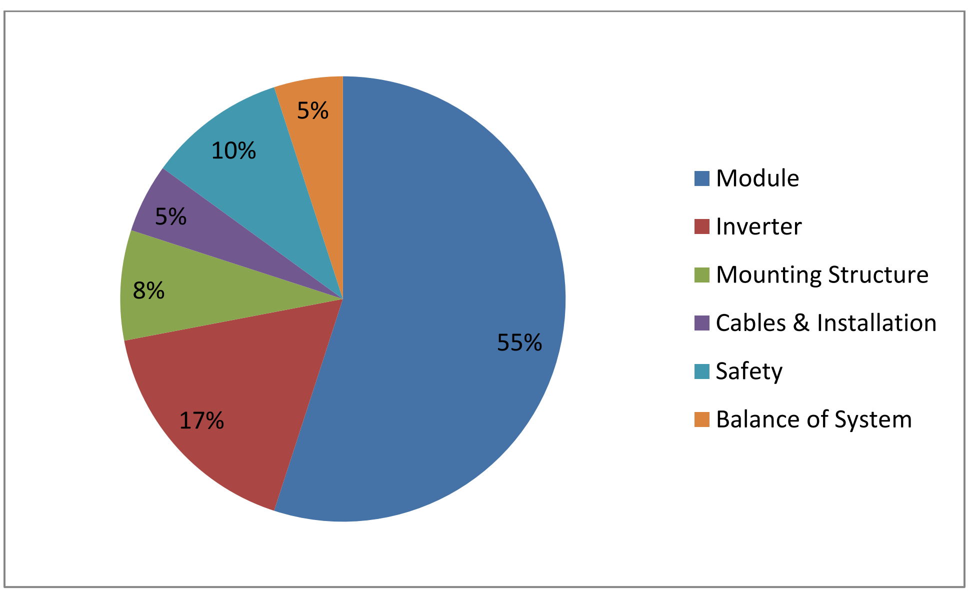

Figure 4-21: Cost breakdown of the system

4.2.1. Monthly Bill Savings (MBS)

Below chart presents amount solar generation would save every month. For months January, February, March, May, November and December; savings would be well above NRs.140, 000 per month. In the monsoon months of mid-June and mid-August, savings comes down to NRs. 105, 000. September showed lowest saving of NRs. 90,000 because it had lowest generation. On average, this system would save NRs. 134,000 per month.

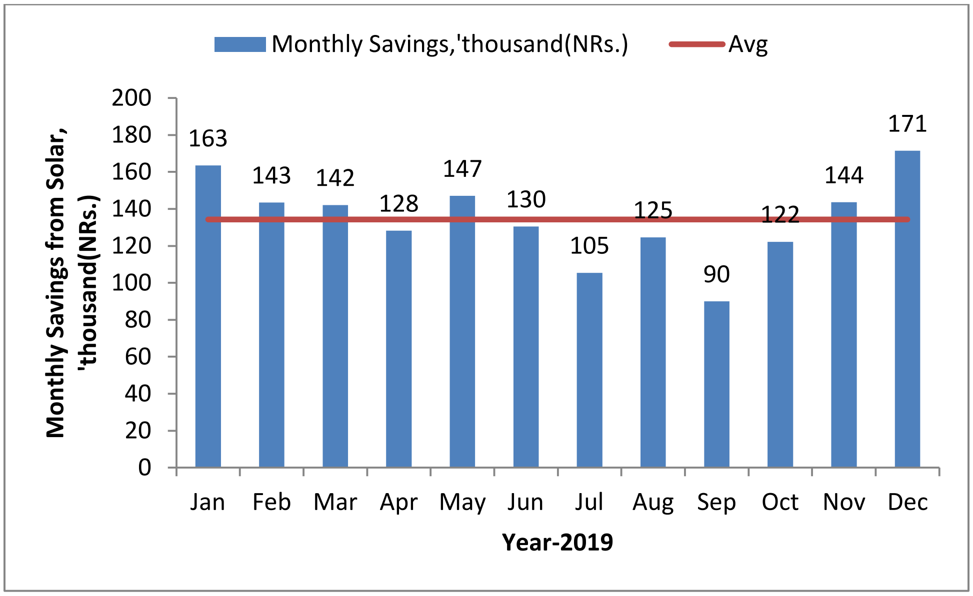

Figure 4-22: Savings from Solar

Hence, it has been calculated, this system would save NRs. 1.60 million annually and would have discounted payback of 5.2 years. Life of the system was considered 20 years. For cash flow, although it would have been easier to calculate with uniform cash flow, however in order to give a realistic picture, the system output would slightly decrease as year progresses. Hence, a 1% decrease in output solar electricity generation per year has been considered here, thereby its same reflection being observed in its cash flow as well (Vikram Solar, 2019). Maintenance cost was assumed to be 1.5% of the total investment cost for the first year and thereby increases by 5% annually. A new inverter has been added in the beginning of 11th year considering life of inverter.

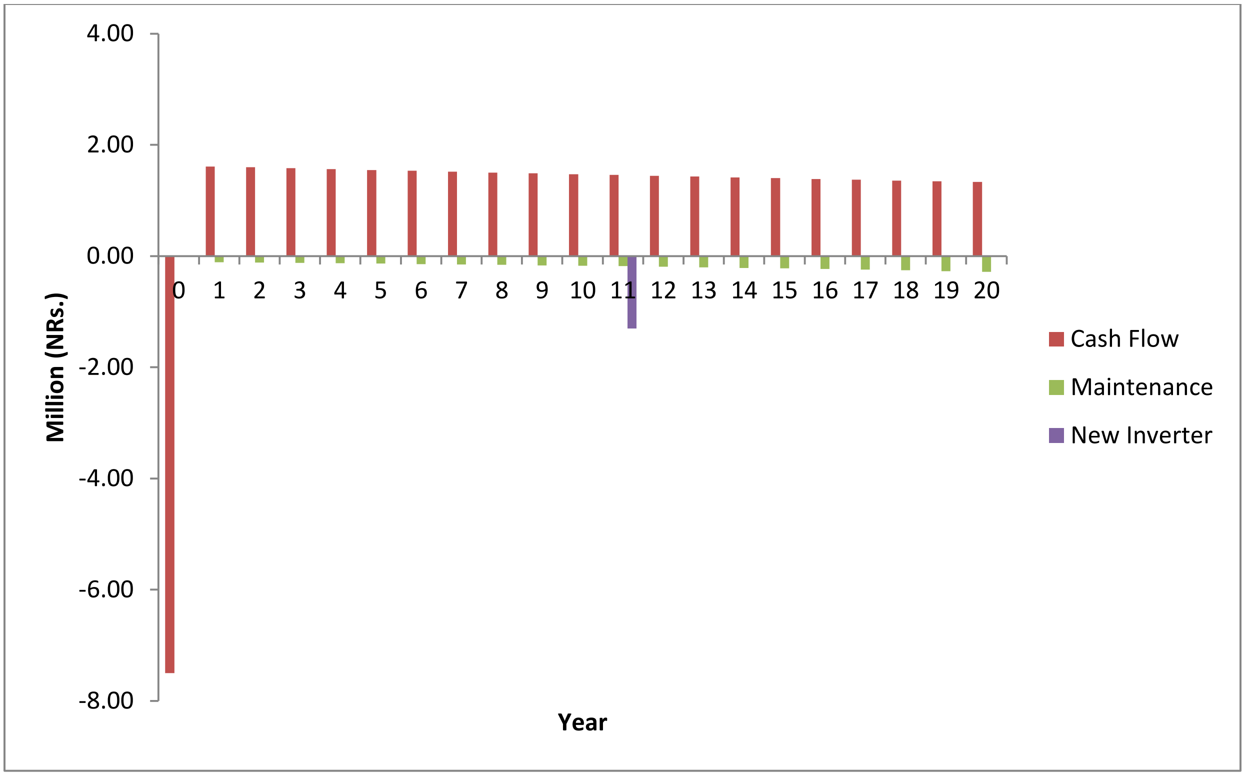

Figure 4-23: Project Cash Flow

4.2.2. Discounted Payback Period (DPBP)

Graph below presents cumulative cash flow of the 64.6 kWp grid-tied solar system at Nepal Telecom, Sundhara, Kathmandu. This shows discounted payback period of the project would be 5.2 years at a discount rate of 12% per year and project life of 20 years. A slight flat line in the 11th year was seen because a new inverter has been added in the beginning of the 11th year. As concept of grid tied solar system just began in Nepal and there are only few reference systems to consider, it is yet to be known how long this grid-tied inverter would perform properly. Hence, to neutralize this doubt, a new inverter cost has been added in the cash flow.

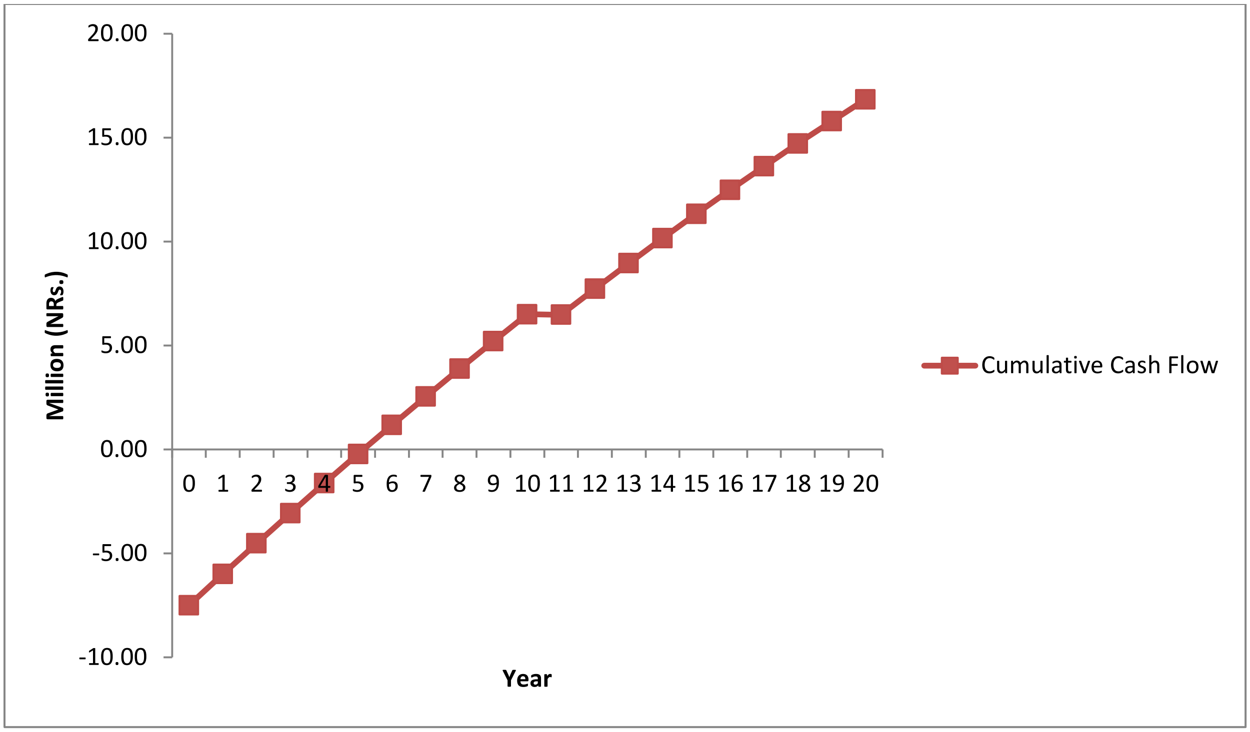

Figure 4-24: Cumulative Cash Flow

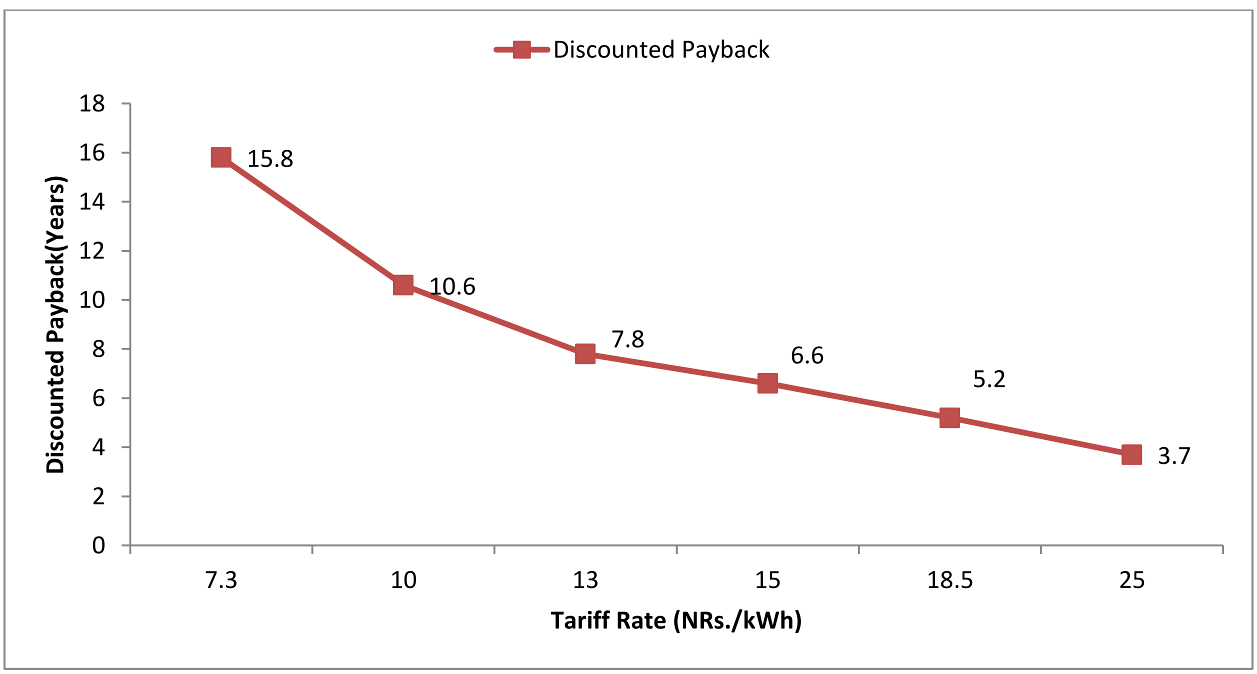

Figure 4-25: Discounted Payback for Different Tariff Rates

Above chart of discounted payback for different tariff rates with shading condition has been developed in order to understand commercialization of this project under different scenario. This project stands at tariff rate of NRs.18.50/kWh with a discounted payback of 5.2 years. However, this does represent only a small fraction of majority customers. Majority electricity customers are in the range of NRs.10 and NRs.13 category which represents households and commercial institutions respectively. It could be observed from the chart, this category of the customers would have discounted payback in about 10.6 and 7.8 years respectively. However, current rate of feed-in tariff (FIT) of Nepal Government is NRs.7.30.That will give discounted payback within around 15.8 years which is a long time for any investor to invest. Hence, Nepal Government should re-visit its feed-in tariff (FIT) rate if it aims to promote grid tied solar system in Nepal.

Chart below is of discounted payback for different tariff rates with no shading condition have been developed in order to understand commercialization of this project under different scenario. This project stands at tariff rate of NRs.18.50/kWh with a discounted payback of 4.4 years. However, this does represent only a small fraction of majority customers. Majority electricity customers are in the range of NRs.10 and NRs.13 category which represents households and commercial institutions respectively. It could be observed from the chart, this category of the customers would have discounted payback in about 9.1 and 6.6 years respectively. However, current rate of feed-in tariff (FIT) of Nepal Government is NRs.7.30.That will give discounted payback within around 14.3 years which is a long time for any investor to invest. Hence, still Nepal Government should re-visit its feed-in tariff (FIT) rate if it aims to promote grid tied solar system in Nepal.

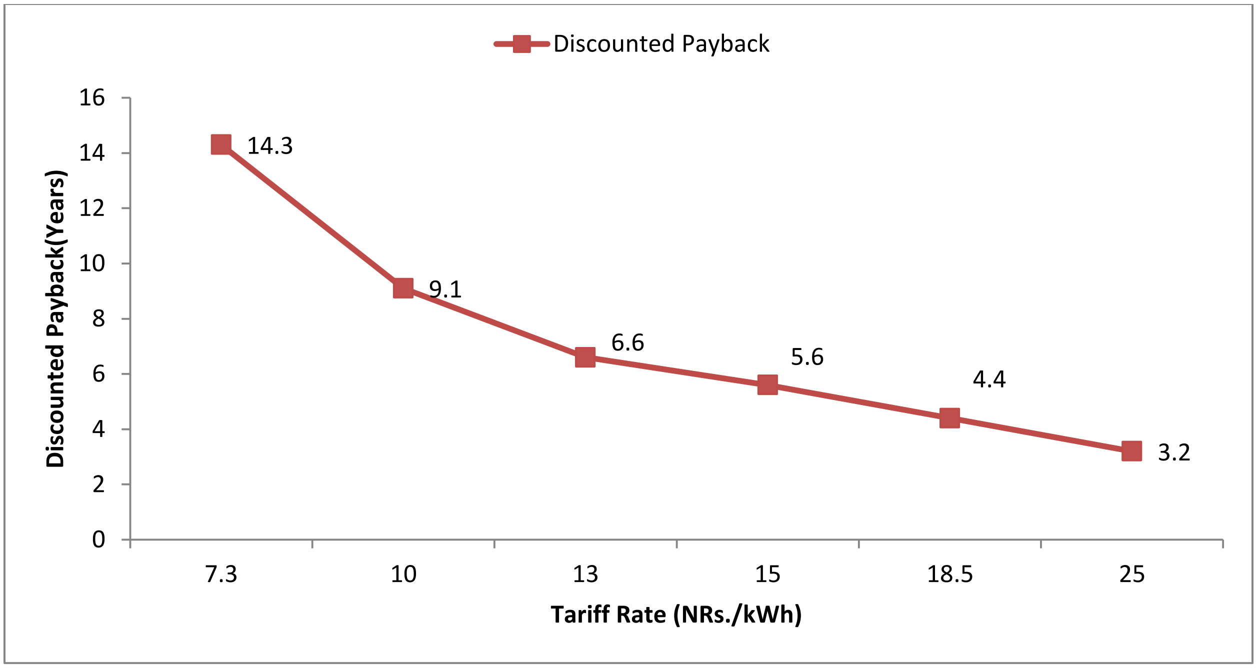

Figure 4-26: Discounted Payback for Different Tariff Rates with no shading condition

4.2.3. Net Present Value (NPV)

Graph below shows net present value (NPV) of the 64.6 kWp grid-tied solar project at Nepal Telecom, Sundhara, Kathmandu at a discount rate of 12% is NRs.2.06 million. At a discount rate of 8%, 14% and 16%, NPV will be NRs.4.72 million, NRs.1.13 million and NRs.0.38 million respectively. NPV value would be negative at the discount rate of 18%.

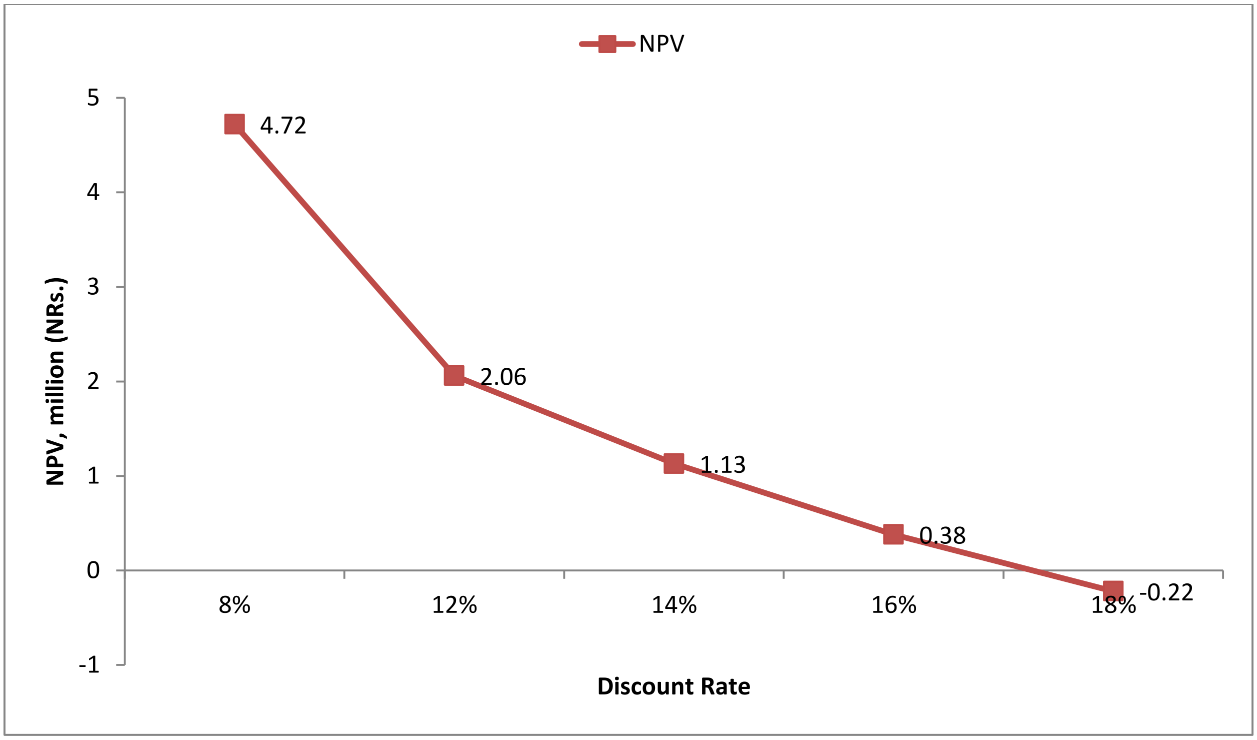

Figure 4-27: Net Present Value

4.2.4. Internal Rate of Return (IRR)

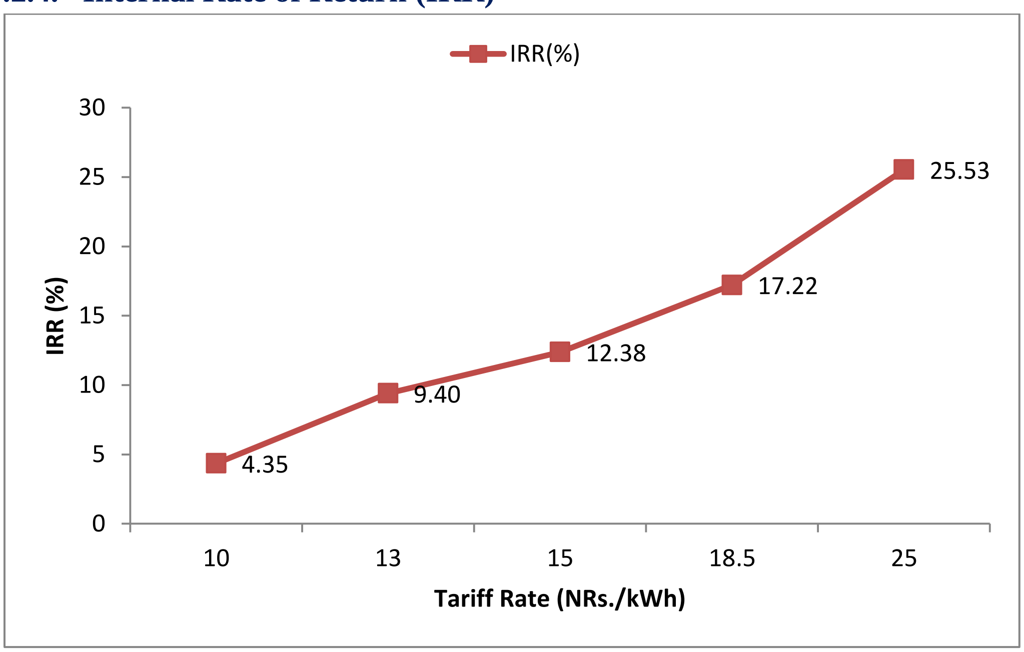

Figure 4-28: Internal Rate of Return

Above chart shows that internal rate of return for Nepal Telecom, Sundhara, Kathmandu would be 17.22% as it is being charged with electricity tariff of Rs.18.5/ kWh. However, if the project is analyzed for commercial (Rs.13/kWh) and residential (Rs.10/kWh) consumers, IRR will be 9.89% and 4.84% respectively. For the commercial sector, IRR was at a considerable rate, however for residential, some kind of government support would be necessary to make it more attractive financially.

4.2.5. Levelized Cost of Energy (LCOE)

For a project life of 20 years, LCOE was found to be Rs.17.97/kWh at a discount rate of 12%. This shows grid tied solar system in Nepal is financially feasible in sectors having dedicated feeder lines, without any subsidy. At an increased discount rate of 14% and 16%, LCOE would be Rs.20.21/kWh and Rs.22.59/kWh respectively while a decreased discount rate of 8% and 4.5%, LCOE would be Rs.13.93/kWh and Rs.10.94/kWh respectively. At a discount rate of 8%, LCOE comes close to commercial clients, and hence this system would be economically feasible to introduce in this sector with some kind of subsidy. In 2015, Government of Nepal (GoN), introduced special discount rate of 4.5% for commercial sectors to buy solar systems for the promotion of solar in Nepal. However, at that time, there was less awareness about grid-tied system, so the scheme did not see success and it was rolled back. The importance of scheme is much more at the current times as it would make the system more attractive financially. In 2019, Government of Nepal has re-introduced a policy (50% subsidy in interest rate for grid connected solar system) similar to the one in 2015 (AEPC, 2019). Hence, this initiative if implemented aggressively, grid-tied solar system could gain much more acceptance in Nepal.

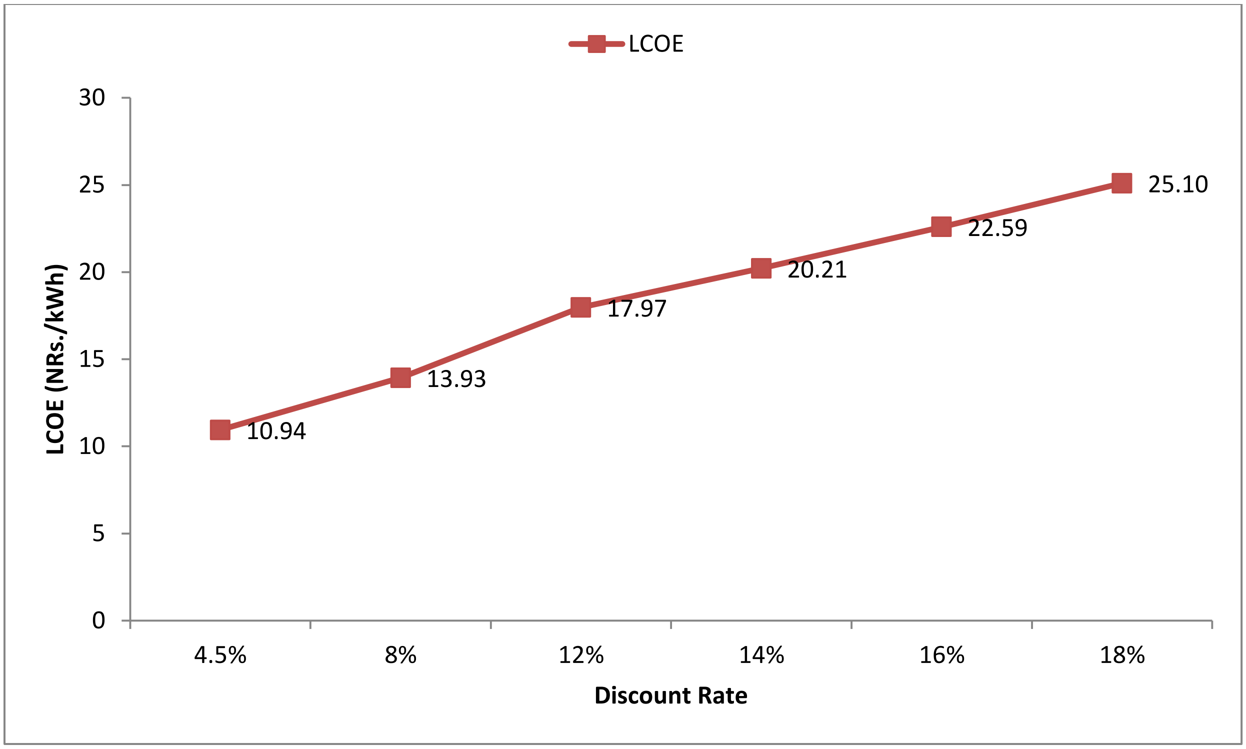

Figure 4-29: Levelized Cost of Electricity

4.2.6. Summary of economic performance parameters

Summary of economic performance parameters of 64.6 kWp grid tied solar system were presented below:

Table 4.3: Summary of economic performance parameters

S.N.	Economic Parameters	Value
1	Initial Investment (million NRs.)	7.50
2	Discount Rate (%)	12
3	Project Life (Years)	20
4	Monthly Saving (thousand NRs.)	134
5	Yearly Saving (million NRs.)	1.60
6	Discounted Payback Period (Years)	5.2
7	Net Present Value, NPV (million NRs.)	2.06
8	Internal Rate of Return, IRR (%)	17.22
9	Levelized Cost of Energy, LCOE (NRs./kWh)	17.97

Grid tied solar system is relatively new technology for Nepal because it requires continuous supply of electricity in the grid line for its operation and this scenario has been recently developed in Nepal. Results of this thesis show this technology is now getting ready for commercialization in the country. Before this, few researches on this topic have been done but it mainly focused on technical feasibility of the system. This research showed grid tied solar systems are gradually becoming technically and economically feasible in Nepal. Findings also show this technology would be more attractive for commercial and residential clients with some support mechanisms from the government. Support mechanisms from Nepal Government have been also formulated and so now needs to be effectively implemented. Hence, grid tied solar system could play an important role in driving Nepal to the direction of energy security.

5. CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1.Conclusions

The conclusions of this research on 64.6 kWp grid tied solar system at Nepal Telecom, Sundhara, Kathmandu were as follows:

Simulated values of total energy generated (E_{AC}), reference yield (Y_R), final yield (Y_F), performance ratio (PR), capacity utilization factor (CUF), overall system efficiency (η_{system}), normalized energy losses (L_T) were 257 kWh/day, 4.66 kWh/kW/day, 3.99 kWh/kW/day, 0.857, 16.62 %, 15.02 % and 0.67 kWh/kW/day respectively.

Measured values of total energy generated (E_{AC}), reference yield (Y_R),final yield (Y_F), performance ratio (PR), capacity utilization factor (CUF), overall system efficiency (η_{system}), normalized energy losses (L_T) were 219 kWh/day, 3.94 kWh/kW/day, 3.38 kWh/kW/day, 0.859, 14.09 %, 15.06 % and 0.56 kWh/kW/day respectively.

Comparison of simulated and measured values showed simulated energy generation was relatively higher (14.65%) than measured generation. This was due to higher solar insolation in simulation, thereby resulting in higher simulated energy generation.

Monthly saving, annual saving, discounted payback, NPV, IRR, LCOE of the system were NRs.134,000, NRs.1.60 million, 5.2 years, NRs. 2.06 million, 17.22 % and NRs.17.97/ kWh at a discount rate of 12 % for a project life of 20 years respectively.

5.2.Recommendations

Following are the recommendations for future study on grid-tied solar system:

1. Further study needs to be performed on this system utilizing whole year data for better understanding of energy generation pattern.

2. Panels under the shade from this system should be shifted to no shade areas to optimize output from the system.

3. For further installations, shading should be strictly avoided.

4. While replicating this system at other sites, possibility of automatic cleaning, summer/winter panel inclination change and tracker technology should be considered after analyzing financial parameters. These mentioned technologies can enhance better output from the system.

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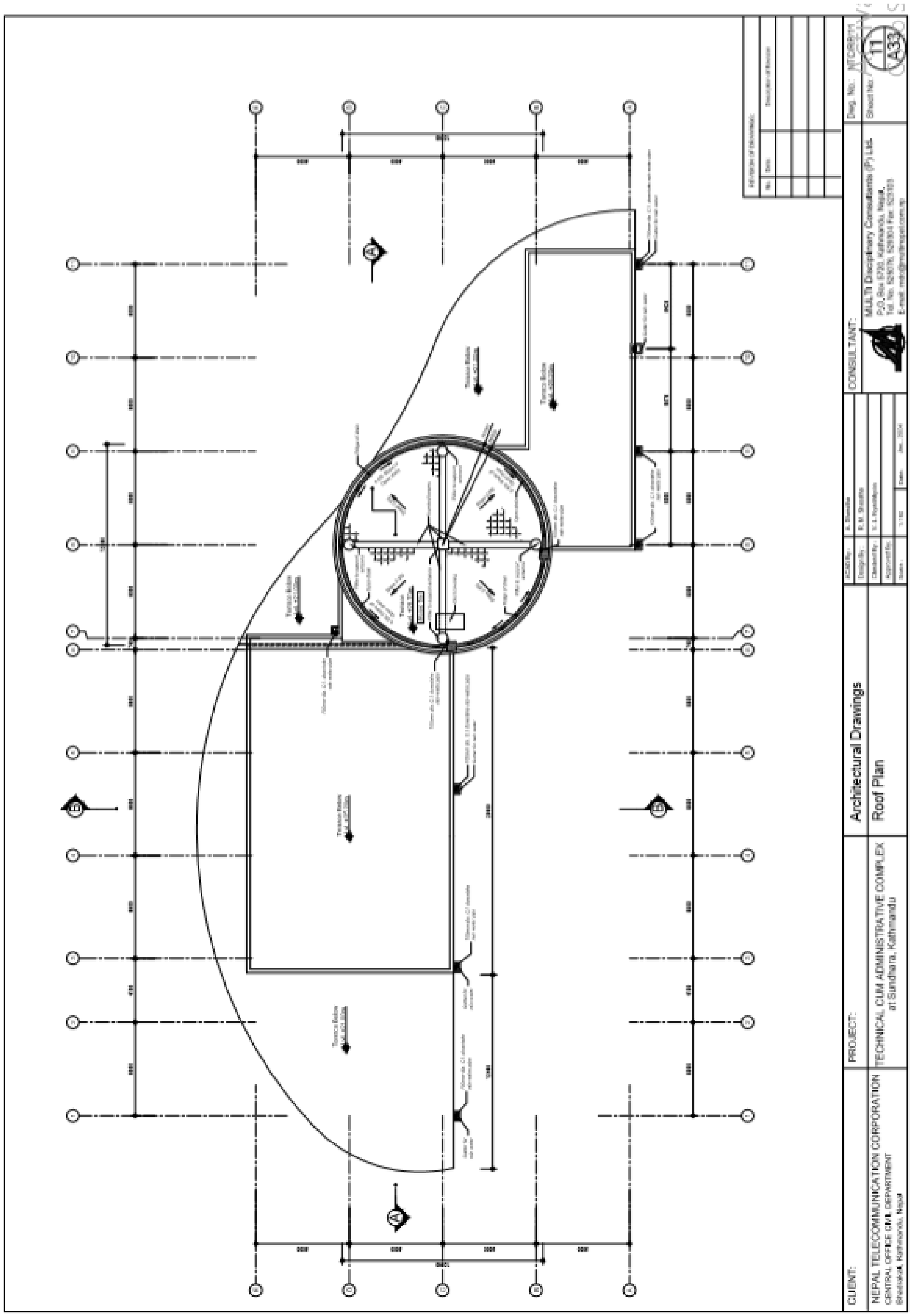
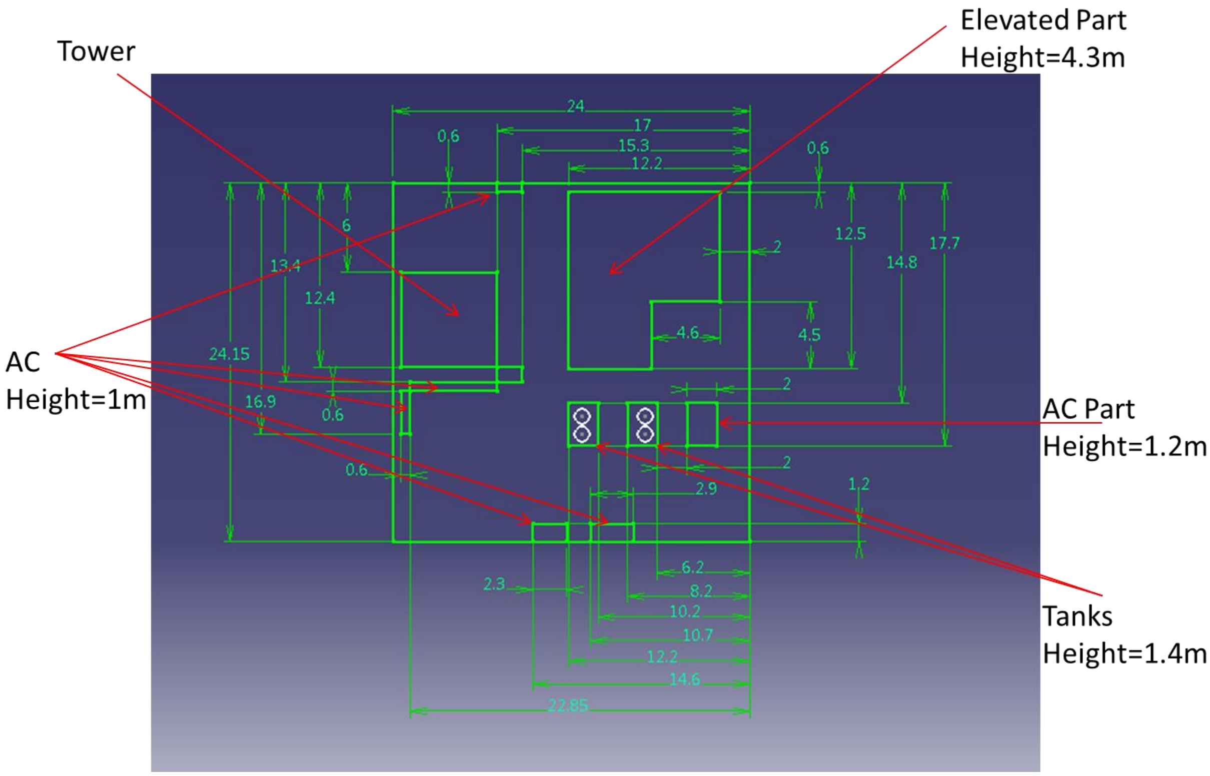
ANNEX

Annex-A: AutoCAD Drawing of Roof 1,2,3 (New Building)



Annex-B: Dimension of Roof 4 (Old Building)



All dimension in metres.

Annex-C: Generation Data (kWh)

Year-2019								
Day	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
1	290	308	299	224	193	242	187	320
2	221	330	315	241	304	183	272	189
3	162	296	92	126	203	182	182	199
4	286	120	267	224	145	132	204	238
5	258	135	330	241	157	212	179	268
6	278	49	286	126	212	193	203	255
7	268	194	275	320	185	218	237	273
8	234	312	272	331	143	207	151	188
9	265	205	256	260	92	221	208	238
10	280	198	252	248	132	206	127	293
11	273	266	242	226	130	247	171	277
12	298	277	224	231	36	262	173	260
13	296	282	168	258	114	207	133	263
14	168	214	261	282	123	241	123	242
15	226	205	298	278	170	163	109	250
16	268	280	273	296	167	159	175	232
17	212	203	299	182	299	235	41	231
18	194	295	315	301	258	186	58	177
19	245	227	92	270	194	233	114	220
20	238	249	267	252	209	173	297	77
21	326	201	330	263	265	256	275	178
22	315	208	286	94	233	295	138	238
23	297	223	275	215	180	178	227	93
24	258	272	272	215	38	237	148	204
25	193	174	256	284	179	219	99	94
26	140	176	252	156	175	256	121	211
27	321	252	242	233	223	311	106	229
28	310	265	224	219	235	211	108	146
29	173	244	168	246	219	187	118	172
30	115	269	261	211	268	288	178	162
31	272		298		220	195		190
32								

Annex-D: Simulation Report (with no shading)

Grid-Connected System: Simulation parameters

Project : **Sundhara_02_NASA**

Geographical Site		**Kathmandu**		Country	**Nepal**
Situation		Latitude	27.70° N	Longitude	85.32° E
Time defined as		Legal Time	Time zone UT+5.8	Altitude	1289 m
		Albedo	0.20		
Meteo data:		**Kathmandu**	NASA-SSE satellite data 1983-2005 - Synthetic		

Simulation variant : **New simulation variant**

Simulation date 19/11/19 04h40

Simulation parameters	System type	**No 3D scene defined, no shadings**		
Collector Plane Orientation	Tilt	30°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			
User's needs :	Unlimited load (grid)			

Activate
Go to Se

PV Array Characteristics

PV module	Si-mono	Model	**Somera VSM.72.340.03.04**		
Original PVsyst database		Manufacturer	Vikram Solar		
Number of PV modules		In series	19 modules	In parallel	10 strings
Total number of PV modules		Nb. modules	190	Unit Nom. Power	340 Wp
Array global power		Nominal (STC)	**64.6 kWp**	At operating cond.	58.4 kWp (50°C)
Array operating characteristics (50°C)		U mpp	655 V	I mpp	89 A
Total area		Module area	**369 m²**		

Inverter	Model	**Solar Inverter M80H (480 VAC)**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	80.0 kWac
			Max. power (=>35°C)	88.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	80 kWac
			Pnom ratio	0.81

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	124 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

PVsyst TRIAL

Grid-Connected System: Main results

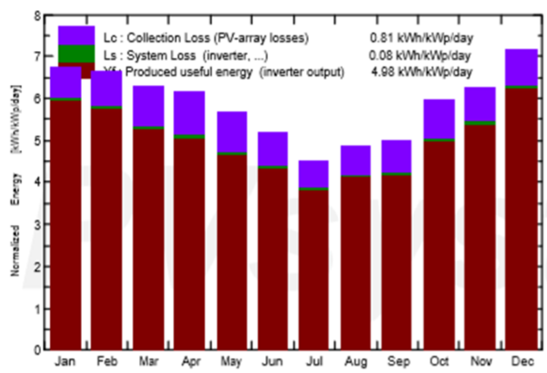
Project : **Sundhara_02_NASA**

Simulation variant : **New simulation variant**

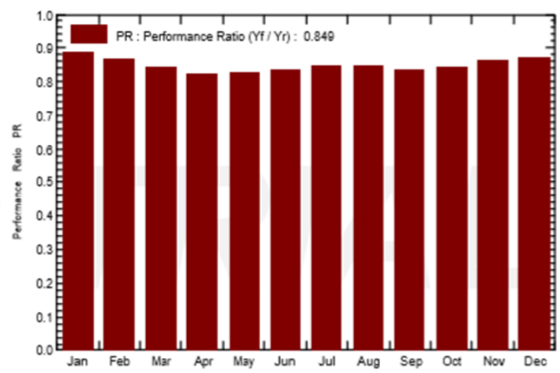
Main system parameters	System type	**No 3D scene defined, no shadings**		
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	Somera VSM.72.340.03.04	Pnom	340 Wp
PV Array	Nb. of modules	190	Pnom total	**64.6 kWp**
Inverter	Model	Solar Inverter M80H (480 VAC)		80.0 kW ac
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**117.5 MWh/year**	Specific prod.	1818 kWh/kWp/year
	Performance Ratio PR	84.95 %		

Normalized productions (per installed kWp): Nominal power 64.6 kWp



Performance Ratio PR



New simulation variant

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
January	138.4	25.99	8.90	208.2	204.0	12.06	11.90	0.885
February	141.1	33.94	13.33	186.5	182.7	10.59	10.44	0.867
March	170.2	59.44	18.84	194.5	189.0	10.74	10.58	0.842
April	184.2	63.81	23.70	185.1	178.9	9.98	9.83	0.822
May	191.5	79.08	25.06	175.6	169.0	9.51	9.36	0.825
June	175.0	87.38	24.25	155.2	148.9	8.54	8.39	0.837
July	156.2	84.75	23.40	140.3	134.5	7.79	7.65	0.844
August	159.0	81.82	23.27	151.5	145.6	8.40	8.26	0.844
September	140.1	61.07	22.40	149.6	144.7	8.23	8.10	0.838
October	150.5	50.78	20.34	184.5	180.0	10.18	10.02	0.841
November	131.7	34.48	15.56	187.9	183.7	10.59	10.45	0.861
December	139.0	18.95	11.06	221.8	217.4	12.65	12.48	0.871
Year	1876.7	681.50	19.20	2140.7	2078.6	119.26	117.47	0.849

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

PVsyst TRIAL

Grid-Connected System: Loss diagram

Project : **Sundhara_02_NASA**

Simulation variant : **New simulation variant**

Main system parameters	System type	**No 3D scene defined, no shadings**		
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	Somera VSM.72.340.03.04	Pnom	340 Wp
PV Array	Nb. of modules	190	Pnom total	**64.6 kWp**
Inverter	Model	Solar Inverter M80H (480 VAC)		80.0 kW ac
User's needs	Unlimited load (grid)			

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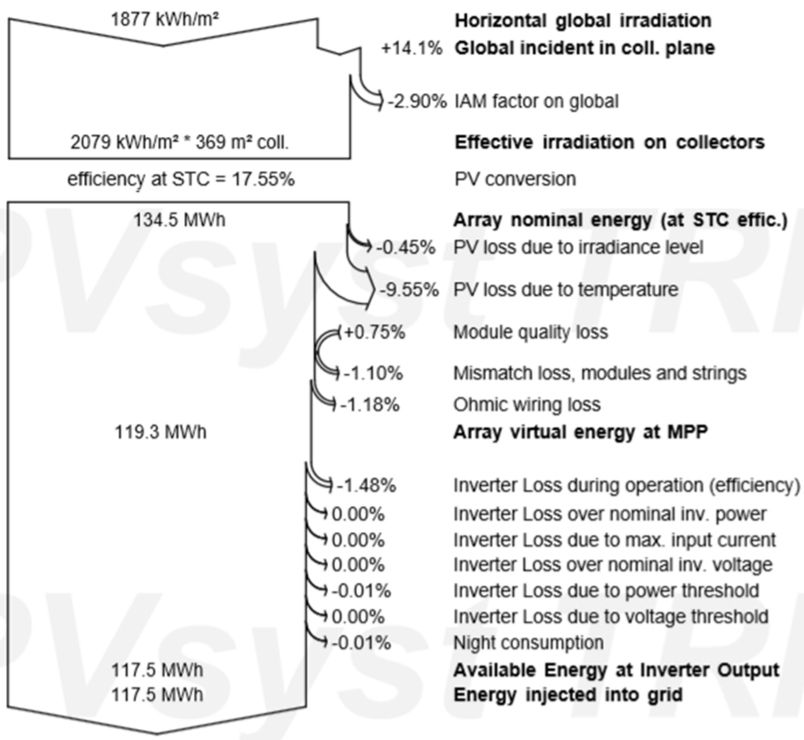
Loss diagram over the whole year



Annex-E: Simulation Report (with shading)

Grid-Connected System: Simulation parameters

Project : **NTC Sundhara_01**

Geographical Site	**Kathmandu**		Country	**Nepal**
Situation	Latitude	27.70° N	Longitude	85.32° E
Time defined as	Legal Time	Time zone UT+5.8	Altitude	1289 m
	Albedo	0.20		
Meteo data:	**Kathmandu**	NASA-SSE satellite data 1983-2005 - Synthetic		

Simulation variant : **New simulation variant_02**

Simulation date 19/11/19 04h34

Simulation parameters	System type	**Sheds on a building**		
Collector Plane Orientation	Tilt	30°	Azimuth	0°
Sheds configuration	Nb. of sheds	16	Identical arrays	
	Sheds spacing	3.30 m	Collector width	1.98 m
Shading limit angle	Limit profile angle	31.9°	Ground cov. Ratio (GCR)	59.9 %
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	According to strings		Electrical effect	100 %
	Shadings of thin objects		Electrical effect	40 %
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module Si-mono	Model	**Somera VSM.72.340.03.04**		
Original PVsyst database	Manufacturer	Vikram Solar		
Number of PV modules	In series	19 modules	In parallel	10 strings
Total number of PV modules	Nb. modules	190	Unit Nom. Power	340 Wp
Array global power	Nominal (STC)	**64.6 kWp**	At operating cond.	58.4 kWp (50°C)
Array operating characteristics (50°C)	U mpp	655 V	I mpp	89 A
Total area	Module area	**369 m²**		
Inverter	Model	**Solar Inverter M80H (480 VAC)**		
Original PVsyst database	Manufacturer	Delta Energy		
Characteristics	Operating Voltage	200-800 V	Unit Nom. Power	80.0 kWac
			Max. power (=>35°C)	88.0 kWac
Inverter pack	Nb. of inverters	2 * MPPT 50 %	Total Power	80 kWac
			Pnom ratio	0.81

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	124 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

PVsyst TRIAL

Grid-Connected System: Main results

Project : **NTC Sundhara_01**

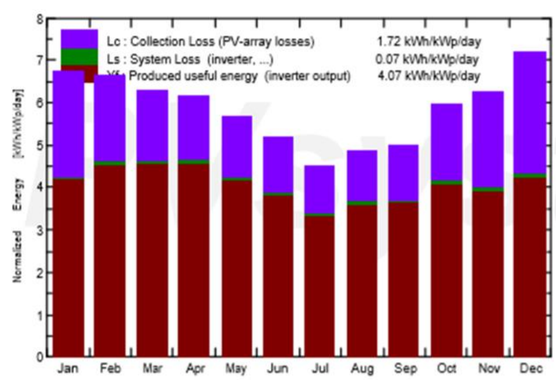
Simulation variant : **New simulation variant_02**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Shadings of thin objects		Electrical effect	100 %
	Shadings of thin objects		Electrical effect	40 %
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	Somera VSM.72.340.03.04	Pnom	340 Wp
PV Array	Nb. of modules	190	Pnom total	**64.6 kWp**
Inverter	Model	Solar Inverter M80H (480 VAC)		80.0 kW ac
User's needs	Unlimited load (grid)			

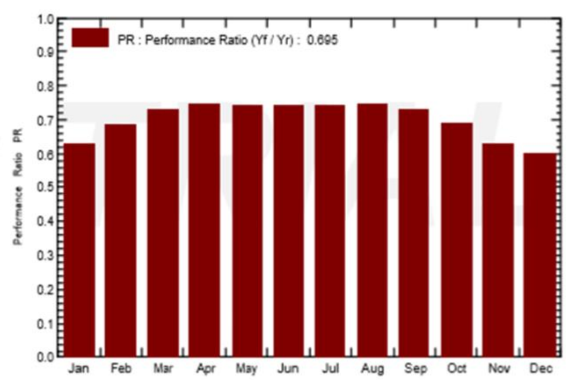
Main simulation results

System Production	**Produced Energy**	**96.05 MWh/year**	Specific prod.	1487 kWh/kWp/year
	Performance Ratio PR	69.45 %		

Normalized productions (per installed kWp): Nominal power 64.6 kWp



Performance Ratio PR



New simulation variant_02

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
January	138.4	25.99	8.90	208.2	155.0	8.556	8.434	0.627
February	141.1	33.94	13.33	186.5	152.5	8.375	8.250	0.685
March	170.2	59.44	18.84	194.5	166.7	9.301	9.160	0.729
April	184.2	63.81	23.70	185.1	162.9	9.032	8.892	0.744
May	191.5	79.08	25.06	175.6	152.4	8.548	8.404	0.741
June	175.0	87.38	24.25	155.2	132.1	7.566	7.426	0.741
July	156.2	84.75	23.40	140.3	118.3	6.833	6.702	0.740
August	159.0	81.82	23.27	151.5	128.7	7.399	7.270	0.743
September	140.1	61.07	22.40	149.6	128.0	7.186	7.058	0.730
October	150.5	50.78	20.34	184.5	153.5	8.364	8.229	0.690
November	131.7	34.48	15.56	187.9	143.7	7.759	7.644	0.630
December	139.0	18.95	11.06	221.8	159.3	8.701	8.576	0.599
Year	1876.7	681.50	19.20	2140.7	1753.0	97.621	96.046	0.695

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

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Grid-Connected System: Loss diagram

Project : **NTC Sundhara_01**

Simulation variant : **New simulation variant_02**

Main system parameters	System type	**Sheds on a building**		
Near Shadings	Shadings of thin objects		Electrical effect	100 %
	Shadings of thin objects		Electrical effect	40 %
PV Field Orientation	tilt	30°	azimuth	0°
PV modules	Model	Somera VSM.72.340.03.04	Pnom	340 Wp
PV Array	Nb. of modules	190	Pnom total	**64.6 kWp**
Inverter	Model	Solar Inverter M80H (480 VAC)		80.0 kW ac
User's needs	Unlimited load (grid)			

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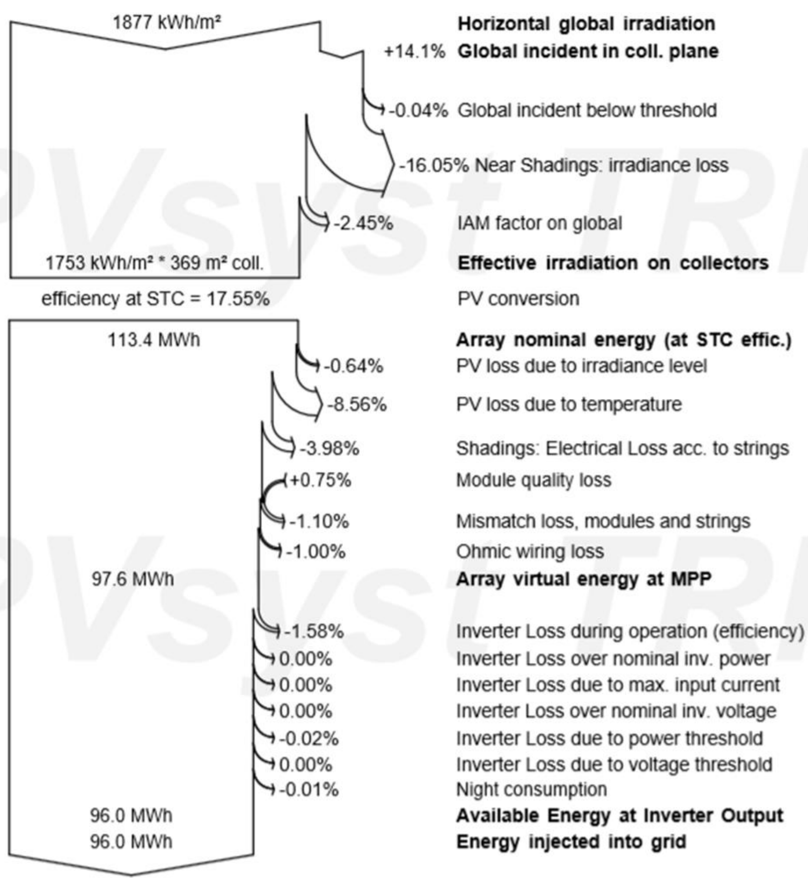
Loss diagram over the whole year



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