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Potential determination, performance and voltage profile analysis of grid connected roof-top solar PV at Bishnumati Distribution Feeder

by

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A THESIS

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled "**Potential determination, performance and voltage profile analysis of grid connected roof-top solar PV at Bishnumati Distribution Feeder**". submitted by Padam Raj Poudel in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Engineering.

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ABSTRACT

This thesis presents the solar roof-top photo-voltaic generation capacity at Bishnumati feeder of Balaju Distribution Control System (DCS) with its performance and voltage profile analysis during grid connection by considering eleven potential commercial and non-commercial buildings. The Building Foot-Print Area (BFA) obtained is 8915.13 m^2 and the actual photo-voltaic area (PVA) is 4190.11 m^2, which is used to install the solar module in the roof of the selected buildings. PVsyst is used for performance analysis, the energy generated by solar array (E_array) and energy supplied to the grid (E_grid) is 1018.319 MWh and 982.039 MWh per year respectively. The performance ratio over the year is 0.74. The average capacity factor of overall installation is obtained as 17 %. ETAP is used for feeder modeling and load flow analysis. Form load flow analysis the minimum grid voltage before solar PV injection is 10.32 kV at a nominal bus voltage of 11 kV. After injection of solar PV into the grid, the minimum bus voltage is improved to 10.53 kV.

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	Alternating Current
AEPC	Alternative Energy Promotion Centre
AM	Air Mass
BFA	Building Foot-print Area
CF	Capacity Factor
DC	Direct Current
DCS	Distribution Control System
ETAP	Electrical Transient Analyser Program
GIS	Geographical Information System
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
MPPT	Maximum Power Point Tracker
NDRI	Nepal Development Research Institute
NEA	Nepal Electricity Authority
PQ	Power Quality
PR	Performance Ratio
PVA	Photo-Voltaic Area
PV	Photo Voltaic
STC	Standard Test Conditions
UNDP	United Nation Development Program

CHAPTER ONE: INTRODUCTION

1.1 Background

Solar Photo-Voltaic (PV) is one of the best sources of renewable energy. Those sources, which are replace by nature within short duration of time is known as the renewable energy sources (RES) e.g., solar PV, solar thermal, wind power, geothermal, tidal energy etc. Also, they are categorized under clean source of energy because they are environment friendly and sustainable source of energy. Due to the increase in energy demand with reduction of fossil fuel, renewable energy power system play the vital role (Reza et al., 2015). With the feature of non-polluting and enough reserve, PV act as a vital role for community to break the energy and environmental crisis which is development trend for the future energy use (Qin and Lin, 2012). One of the problems of RES as all the renewable energy resources except geothermal energy, being climate dependent, the power generated from them is of varying magnitude-even sometimes no power is generated at all. The other drawbacks are the poor power quality and the high cost of generation, which are the big challenges for meeting the target of ever-increasing demand of electric power by renewable energy systems in an efficient and effective way (Pali and Vadhera, 2016). So, grid connection of RES plays the major role to improvement power quality (PQ).

According to the Sustainable Development Goal (SDG7), “Ensure access to affordable, reliable, sustainable and modern energy for all”, this goal is only achieved only when RES is utilized. The reserve of the conventional fossil fuels is limited and in near future they are completely vanished and, in such situation renewable energy full fill the need of modern and sustainable energy. To fulfil this future requirement, it is necessary to find out how much power/energy can be generated from specific areas along with its impact on grid connection. This thesis completely deals with potential determination of solar roof-top PV of large scale commercial and non-commercial building Bishnumati feeder of Balaju distribution centre.

Concept of energy mix is widely existing in world wise, along with Nepal declared that energy mix in grid should be at least 15%. In the future, RES are inevitable and play the great role in energy sector. All most all the RES are weather dependent and termed as renewable energy intermittency. The solar PV is widely weather dependent, during night-time there is no power generated and in daytime also power output is dependent of solar irradiation, cell temperature, insolation, shading etc.in such situation the maximum power is extract by Maximum Power Point Tracker (MPPT). If PV module unable to generates its rated power, the task of a MPPT in a PV energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions (Chermitti et al., 2012).

While connecting the roof-top solar in grid its performance and voltage profile analysis play the important role. According to International Electrotechnical Commission (IEC) 61724 standard, the final yield (Y_f), array yield (Y_a), reference yield (Y_r), energy efficiency, and total power generated by the PV system E_{AC} are the major consideration under performance analysis. Currently, Government of Nepal focuses on renewable source of energy mainly on solar PV. If private company or government itself going to install the large-scale roof-top photo-voltaic system, potential determination and performance analysis is the crucial parameter before investing.

1.2 Problem Statement

The term reliable and modern energy focuses on the renewable energy sources like as Solar PV, wind, geo-thermal etc. among them solar PV play the vital role in country like Nepal because Nepal has 4 to 6 peak sun and around 300 sunshine day in a year (AEPC, 2021). Government of Nepal also focuses on the energy mix concept to fulfil the SDG, but there is no any micro level study to find out, how much power can be generated through solar PV. Solar power can be generated from land and roof-top of commercial/residential building /houses and it is very crucial to find how much power can be generated from existing infrastructure. Only finding solar PV potential considering the certain factor is not satisfactory because the major problem is how it performs throughout the year? Because actual energy generation depend on the how it performs throughout the year (Attari et al., 2016). This thesis is focus on solar PV power generation capacity of Bishnumati feeder of Balaju distribution centre from major roof-top of residential/commercial building/houses. The major problem of renewable energy sources is renewable energy (solar PV, wind etc) intermittency (Chermitti et al., 2012). Solar PV greatly faces intermittency problem, power is not generated in night-time and power generated during day-time changes according to irradiance level and temperature such that output power is varies continuously (Durgadevi et al., 2011). The output of the solar cell is DC and need an inverter to convert in to grid compatible AC. The frequency and voltage level of solar PV is control though inverter also it unable to supply reactive power to the utility grid, due to this there might be difficulty and may arise reliability issues. So, impact analysis is necessary to find out possible solution and to reduce adverse effect after grid connection of roof top solar PVs.

1.3 Objective

The main objective is to determine solar PV power generation capacity at Bishnumati feeder of Balaju distribution centre by considering some of commercial and non-commercial building along with its performance and voltage profile analysis.

Specific objectives

- To find out the solar PV roof-top potential of Balaju distribution feeder
- To evaluate actual energy yield by the system
- To evaluate the performance parameters of solar PV system
- To analyze voltage profile and losses before and after photovoltaic injected to grid

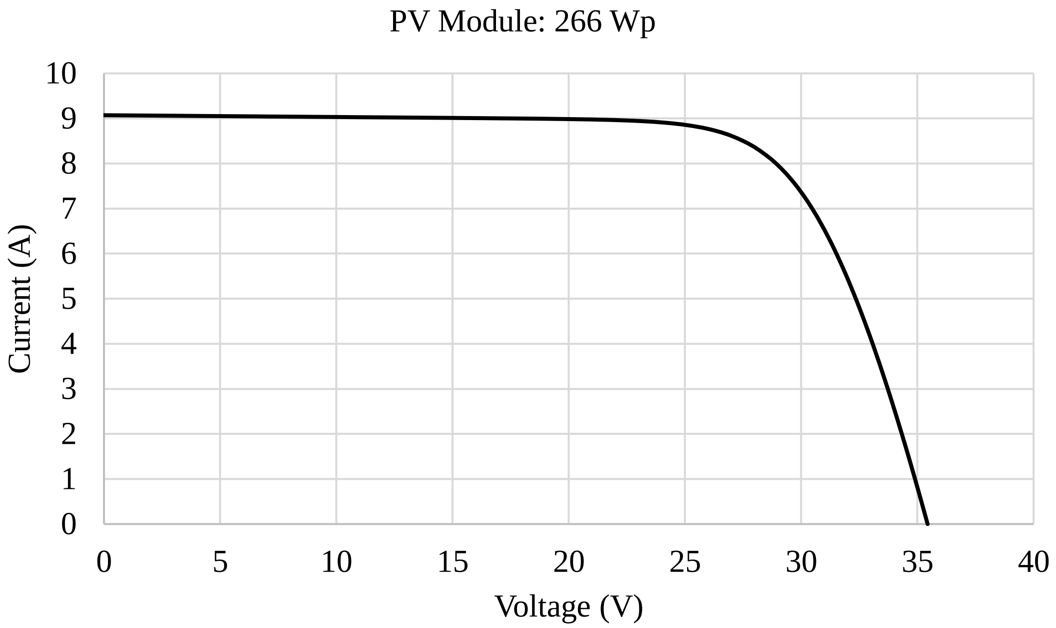
1.4 Limitation

The entire thesis will be focuses on to find output power generation capacity of large-scale building and its performance and voltage profile analysis of roof-top solar PV on grid connection at Bishnumati distribution feeder. Most of the data are taken from secondary sources so, there may be minor deviation in result. Effect of residential buildings on solar power generation and its effect on grid is not considered.

CHAPTER TWO: LITERATURE REVIEW

2.1 Solar PV

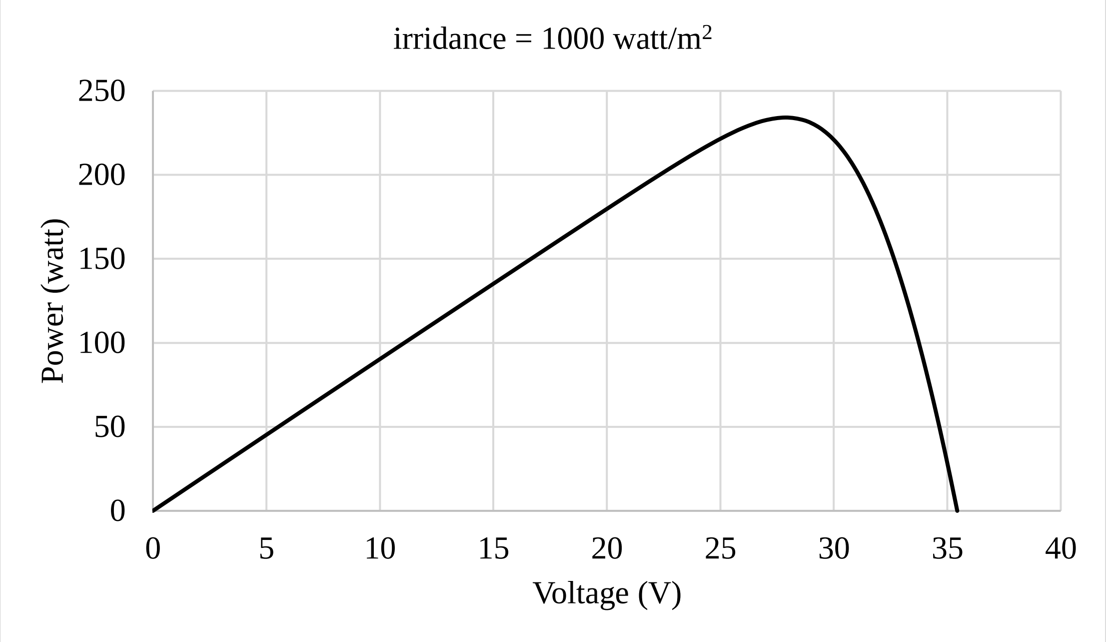
The increasing political and environmental problems related to the fossil fuel are the main drawbacks of this energy source exploitation. A way to overcome these difficulties and to satisfy the growing electricity demand around the world is the use of photovoltaic systems which allow converting solar energy into electricity from sunlight (Charfi et al., 2018). It is the most modern and sustainable source of energy. The output of the solar PV depends on the environmental factors like as solar irradiance, cell temperature and air mass (AM). Due to these factor output voltage and current is varied and hence output power also the I-V characteristic of solar PV at constant solar irradiance is shown in Figure 2.1.



(Charfi et al., 2018)

Figure 2.1 Current vs Voltage graph of solar PV

The P-V curve of solar PV is shown in Figure 2.2. the output up to maximum current and voltage point is increase linearly after that it start decrease as shown in Figure 2.1. at maximum power point (MPP) solar panel deliver the maximum power i.e., input impedance and output impedance are matched, and maximum power is delivered. With increase in solar irradiance the output voltage and current are increased and hence, power generated by solar module also increase.



(Charfi et al., 2018)

Figure 2.2 P-V curve of solar PV

2.2 Mathematical modelling circuit of solar PV cell

Photovoltaic solar cell absorbs the sunlight as a source of energy to generate direct current electricity. When the sun hits the semiconductor within the PV cell, electrons are freed and form an electric current. A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorous dopped (N-type) silicon on top and a thicker layer of boron-dopped (P-type) silicon on back side (Premkumar et al., 2020: Singh and Rajput, 2016). The actual mathematical modelling of solar cell is shown in Figure 2.3.

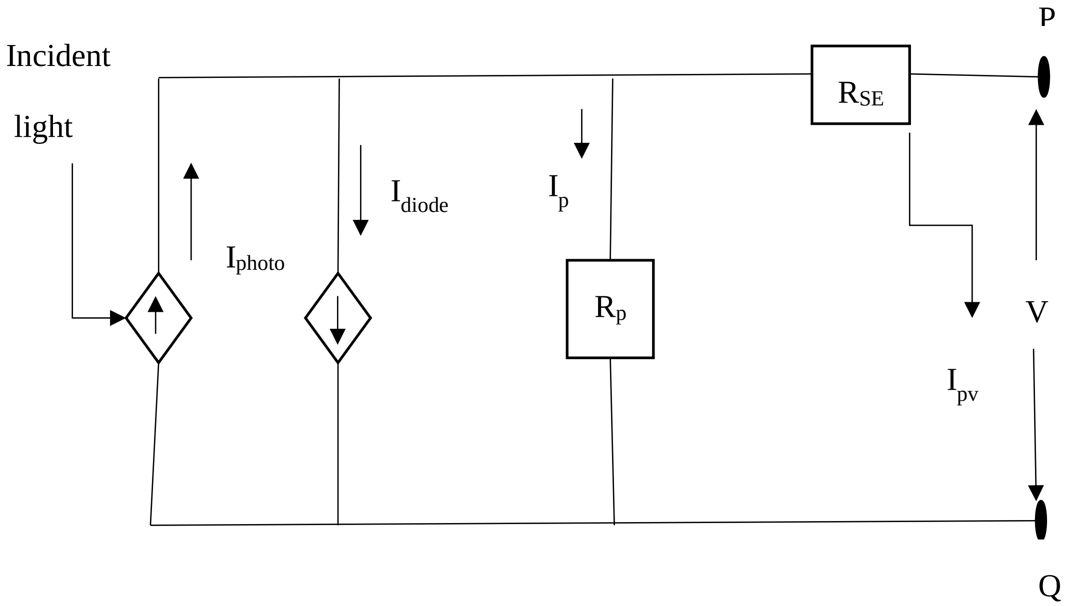
An equivalent circuit of solar cell consists of a one current source, one anti-parallel diode, a shunt, and series resistance (Premkumar et al., 2020). Applying Kirchhoff's current law in the model shown in Figure 2.3.

$$I_{PV} = I_{Photo} - I_{diode} - I_p \qquad \ldots\ldots\ldots\ldots 2.1$$

Where I_{photo} is the photo current, and it is linearly varying with solar irradiance at constant temperature. I_{diode} is the antiparallel diode current and produce the non-linear response on the PV cell. I_p is the current through shunt reactor (Premkumar et al, 2020). Substitute the value of I_{diode} and I_p in equation 2.1.

$$IPV = Iphoto - Io\left(e^{\frac{q(V+Ipv*Rse)}{nkT}} - 1\right) - \left(\frac{V+Ipv*Rse}{Rp}\right) \quad \text{..................2.2}$$

Where, $q = 1.602*10^{-19}$C, n is diode ideality factor, $k = 1.3806503*10^{-23}$ J/K is the Boltzmann constant, I_o is the saturation current of the diode, T is the temperature of the PV cell, R_p and R_{se} represent the shunt and series resistance respectively.



(Premkumar et al., 2020)

Figure 2.3 Mathematical modelling of solar cell Renewable energy potential of Nepal

Nepal is a developing country, having very low potential of conventional (Mainly fossil fuels) source of energy and having huge potential of renewable source of energy mainly solar PV (Sudeep and Zulker, 2017). Conventional energy sources are continually declining, and it costs high for import in county like Nepal. Traditionally, Nepal is mainly dependent on energy sources like as biomass, animal dung, wood etc currently Nepal is hydro dominant. Somehow, hydropower is considered as a renewable source of energy (except large storage hydropower) but it’s long-term future will be uncertain.

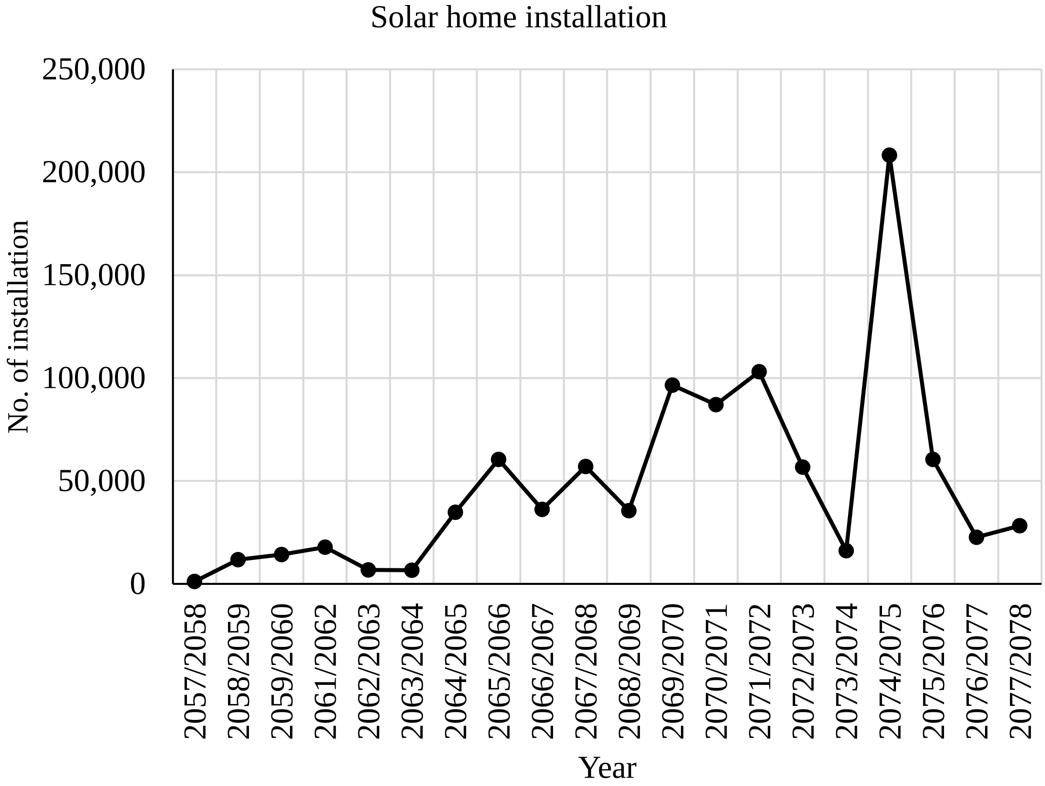
Globally in every decade almost $4^{o}C$ temperature will rises (NDRI, 2017), this adverse effect may badly affect the hydropower due to melting of snow rivers, lakes, and declining precipitation. So, in long run only hydro energy is not sustainable source of energy. According to the SDG goal of UNDP, Nepal also aims to achieve universal access to clean, reliable, and affordable renewable energy solutions by 2030. It is expected to reduce dependence on traditional and imported energy by increasing access to renewable energy (Sudeep and Zulker, 2017).

Nepal can enjoy the huge potential of renewable sources of energy mainly solar photo voltaic because Nepal is blessed with solar resource as it lies at 30^{o} Northern latitude which is ideal and there are over 300 days of sunshine annually. Further the annual average solar insolation is 5.16 kWh/m^2 per day (AEPC, 2021). These conditions are perfect for harnessing solar energy for various conversion technologies. Mainly, application area of solar energy is categorized in two categorized (AEPC, 2021)

- Solar electricity
- Solar thermal

"In 2015, Nepal and the World Bank signed an agreement to invest USD 130 million to develop a 25 MW solar project that will eventually be connected to the national grid. It is the largest renewable energy plant planned in the country" (Sudeep and Zulker, 2017). Currently this plant is in operation in Nuwakot district. Currently most of the solar power is harness by private level in their own homes/building for the alternative of power cut. Privately small-scale solar power plant is devolved and connected to grid, but it is in very small scale. So, actual solar power generation capacity should be determined in government level. Different research show that Nepal has solar potential of around 2100MW and wind potential of 3000 MW (Sudeep and Zulker, 2017), but only little percentage of this potential is harness.

According to AEPC, solar home system installs in between 2057/58 to 2077/78 is shown in Figure 2.4. during staring phase solar home installation is slow and it take pick up during 2074/75, having total installation about 208368 solar home system and its trend going to declining after that it due to easy assessable of hydro and import energy and high initial cost of solar PV. To make solar PV commercialization and to make fully utilization of houses/building roof-top areas some policy and subsidy program should be implemented by government of Nepal. Total home system installation for 20 years period is shown by graph in Figure 2.4.



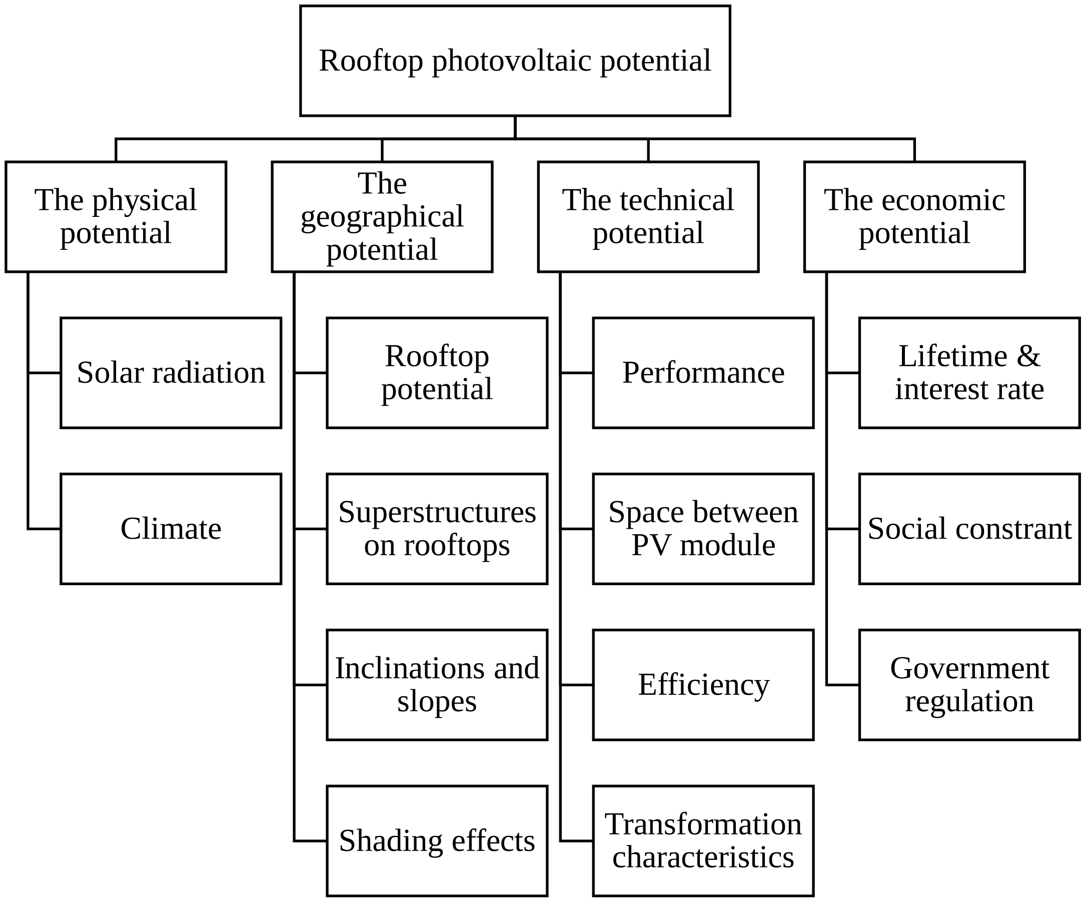
(AEPC, 2021)

Figure 2.4 Solar home installation

2.3 Solar PV potential determination

During potential determination the most important part is the determination of roof-top area. A rigorously founded assessment of the potential of renewable energy is essential for the development of energy policies and regulation (Izquierdo et al., 2008). The most important step for determining the PV potential is defining the data sources and their availability in addition to the methodology selection (Sustainability, 2021). The potential of the roof-top solar PV is further divided into four sub-potentials as shown in Figure 2.5.

Physical potential is the overall solar PV potential of the specific area by considering the area occupied by the selected region and climate data along with daily or monthly radiation data. Current study mainly focusses on finding the geographic potential of solar PV. For this rather than considering the area occupied by the selected region built in area of the structure within the region is consider. Actual solar PV installation area depend on the type and design of building also solar roof-top potential depend on the type of solar PV, solar irradiance, temperature, climate condition and solar photovoltaic area (Singh and Banerjee, 2015).

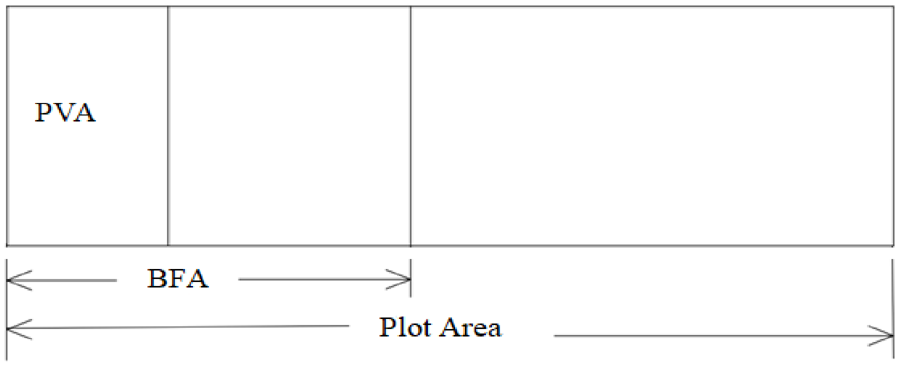


(Singh and Banerjee, 2015)

Figure 2.5 Sub-potentials and their essential factors for rooftop photovoltaic potential determination

The actual solar photovoltaic area from built in area can be determine as shown in Figure 2.6.

. i.e., PVA = BFA*PVA ratio (Singh and Banerjee, 2015).



(Singh and Banerjee, 2015)

Figure 2.6 Correlation between PVA, BFA and Plot Area

2.3.1 Plot area

It is the area occupied by the building i.e., if any structure is built in 100 m^2, then 100 m^2 is the plot area of this building or structure as shown in Figure 2.6.

2.3.2 Building footprint area

It is common for building all plot area is not used for constructing the building some part of it left for parking and free space. The area used for construction of building is known as building footprint area (BFA) and ratio of BFA to plot area is BFA ratio (Singh and Banerjee, 2015) as shown in Figure 2.6.

$$\text{i.e., BFA ratio} = \frac{\text{BFA}}{\text{Plot Area}} \qquad \text{……………2.3}$$

2.3.3 Photovoltaic area

For installing the solar panel only certain area of rooftop is utilized because of shading, ventilation required in building, some essential structure in roof-top etc. after considering these factors the actual area available for solar PV installation is known as Photovoltaic area (Singh and Banerjee, 2015) i.e., mathematically

$$\text{PVA ratio} = \frac{\text{PVA}}{\text{BFA}} \qquad \text{……………2.4}$$

2.4 Performance analysis

Performance analysis is the very crucial parameter for to find actual energy yield, from this study investor can decide to invest or not. According to IEC 61724 standard, the final yield (Y_f), array yield (Y_a), reference yield (Y_r), energy efficiency, and total power generated by the PV system E_{AC} are the major consideration under performance analysis.

2.4.1 Array yield

The array yield (Y_a) is the output energy delivered by the PV module over a definite period (Sharma and Chandel, 2013) and given by

$$Y_a = \frac{E_{DC}}{P_{pv,rated}} \qquad \text{……………2.5}$$

2.4.2 Final yield

The final yield is the ratio of AC energy delivered during a specific period to the rated power of the installation (Al-Otaibi, 2015) and given by

$$Y_{f.d} = \frac{E_{AC}}{P_{pv,rated}} \qquad \text{……………2.6}$$

2.4.3 Reference yield

It the ratio of global solar radiation (H_t) in kwh/m^2 to PV's reference irradiance and given as (Kymakis et al, 2009)

$$\mathrm{Y_r} = \frac{\mathrm{H_t}}{\mathrm{H_g}} \qquad \text{……………….2.7}$$

Where H_g = 1 kw/m^2

2.4.4 Performance ratio

Performance ratio depends on the total losses in the system resulting from conversion operations made by different components as PV modules, inverters, and cables. Weather conditions as ambient temperature are also impacting factors. The performance ratio (PR) can be defined as the final yield divided by the reference yield and is given as (Chaiyant et al., 2009)

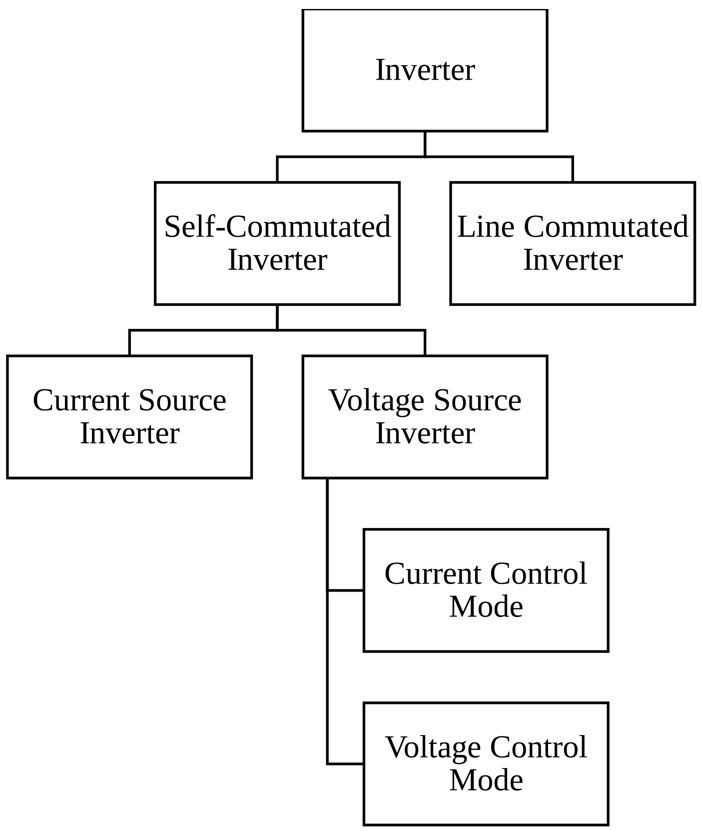
$$PR = \frac{Y_f}{Y_r} \qquad \text{……………2.8}$$

2.4.5 Capacity factor

The Capacity Factor (CF) during a specific period is the AC energy produced by the PV system divided by the AC energy that can be generated if the system operated with its nominal power during that same period. The annual capacity factor is given as (Kymakis et al., 2009: Sharma and Chandel, 2013: Singh and Banerjee, 2015)

$$C.F = \frac{E_{AC}}{P_{pv,rated*24*365}} \qquad \text{……………2.9}$$

2.5 Grid connected inverter



(Jana et al,2017)

Figure 2.7 Classification of inverter

Inverter is the device that convert the fixed or variable dc in to fixed or variable ac. On the basics of its function there are various inverter topologies as shown in Figure 2.7.

Inverter play the inevitable role in grid connected PV system along with conversion from DC to AC it can be used in harmonics elimination with suitable Pulse Width Modulation (PWM) technique. One the basics of phases there are mainly two types of inverters i.e., single phase and three phase inverters. On the basics of signal to be control there are two types of inverters i.e., voltage source and current source inverter. Figure 2.8. show the simple single-phase inverter.

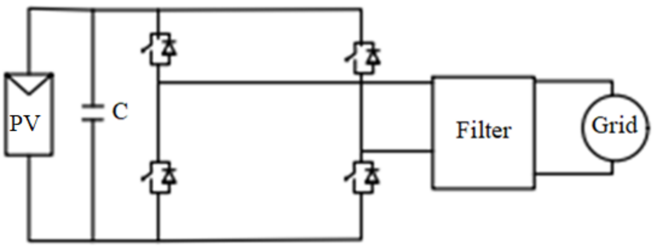


Figure 2.8 Single Phase Grid Connected Inverter

During modelling of grid connected inverter it is important factor to select the switching devices. Nowadays mainly used switching devices are thyristor, MOSFET, IGBT, Power BJT etc. but selection of these devices should be done properly according to switching frequency and power to be handle. Generally, MOSFETS are use in low power and high frequency(20kHz-100kHz) and IGBT for medium to high power and low frequency (below 20 KHz) (Jana et al,2017). Switching loss in MOSFET is less whereas high conduction but its complement is for IGBT. Although thyristor can be used as a switching device but for its proper operation extra switching circuit is required (Hassaine and Begourina, 2020). In inverters using GTOS, switching-off is achieved by applying a negative gate-current pulse. Inverters using transistors, like BJTs, MOSFETs, IGBTs or SITs, can turned off by the control of their base current (Bimbhra, 2016).

From the viewpoint of connections of semiconductor devices, inverters are classified as under (Bimbhra, 2016).

i. Bridge Inverter
ii. Series Inverter
iii. Parallel Inverter

Grid connected inverter involves two major tasks, first one is to ensure the solar modules to operate in maximum power point and second is to inject the sinusoidal current to the grid (Kjaer et al., 2005). The first function is ensured by the MPPT controller and buck-boost converter, and second function is ensured by grid connected inverter and PLL technique.

2.6 Phase locked loop

Phase Locked Loop (PLL) technique has been studied to find out phase and frequency information of grid-connected PV-system for synchronizing the grid voltage and the inverter output current (Yu, 2018). Grid connected PV system has the fastest growth rate in the world energy sector and has started to play the dominant role in energy sector (Yu, 2018). It is very important to match the output phase and frequency of the solar PV system with the grid utility, for this purpose different techniques are used among theme PLL is more reliable to implement.

2.7 Study area

This thesis is entirely focuses on the potential determination, performance, and voltage profile analysis at Bishnumati feeder of Balaju distribution centre. The main reason behind selection of Bishnumati feeder is, at far end of this voltage is reduce greatly and sometime difficult to operate the end user devices. Also, there is industrial area, if power generation is exceeding the demand at residential sector this power can be supplied into industrial sector.

CHAPTER THREE: METHODOLOGY

Entire work is divided into different section, first section deals with site selection and potential area determination for solar PV installation by taking eleven, commercial and large-scale building at Bishnumati feeder of Balaju DCS. Second stage study performance parameter of the grid connected solar PV like annual energy generation, energy generation variation, final yield, array yield, reference yield performance ratio etc.

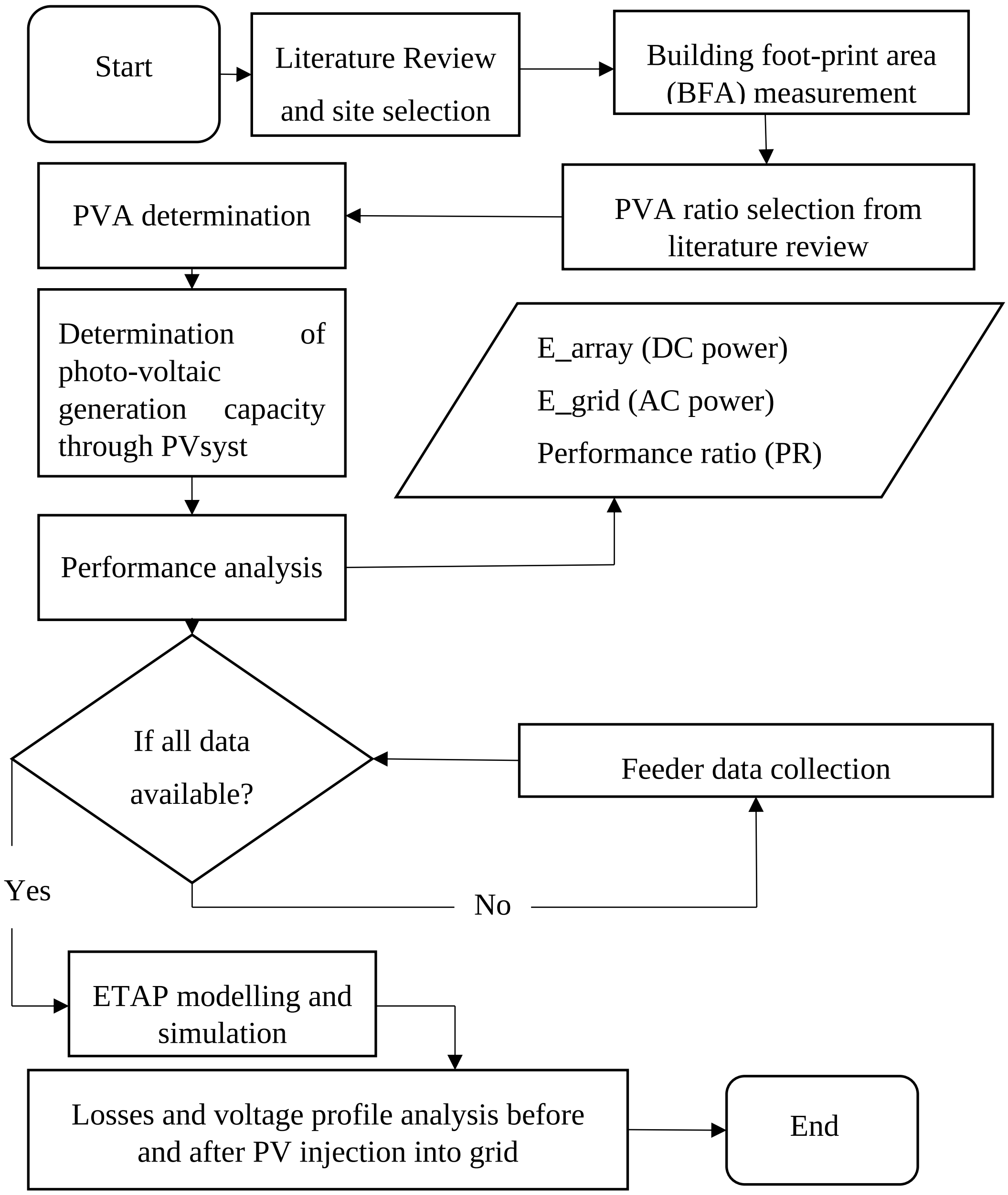


Figure 3.1 Flow chart of entire thesis work

Third stage study about grid voltage profile, active and reactive power flow, line losses and bus angle before and after PV injection into grid. The overall workflow diagram is shown Figure 3.1.

For potential area determination google earth pro and cad-mapper is used. Area of some buildings are measured manually, which set the reference for validation. For designing solar system and performance analysis PVsyst software is used. After finding actual energy generation from PVsyst, feeder data are collected from loss reduction department under Nepal electricity authority (NEA).

QGIS and GRASS GIS is used to find out the feeder parameter like as transformer location and it's rating, line length and type of conductor, line resistance and inductance, buses, load etc. GIS files is prepared by NEA. After finding feeder parameter load-flow analysis is done through ETAP. after load flow analysis the main parameter obtain are bus voltage, active and reactive power flow, line losses, bus angle etc. during load flow analysis feeding substation i.e., Balaju substation is taken as slack bus and all other are PQ buses.

In ETAP modelling total of 57 buses are formed and from load flow analysis voltage of all buses is obtain, which is used for construction of voltage profile of grid before injection of solar photo-voltaic into the grid. The solar power from the different selected building is injected into the grid and again load flow analysis is done. From load flow analysis line active and reactive power flow, line losses, bus angle and different bus voltage is obtained. From bus voltage again voltage profile is constructed, this voltage profile is compared with voltage profile which is obtain before penetration of solar photo-voltaic into grid and impact of penetration of solar photo-voltaic into grid is studied.

3.1 Site selection

For this research work Bishnumati feeder of Balaju substation is selected, which is located at Tarakeshwor municipality. Bishnumati feeder is feed by the Balaju substation. The satellite view of Tarakeshwor municipality is shown in Figure 3.2. The voltage drop at far end of Bishnumati feeder is high which cause the operational difficulty in end user devices, the voltage profile at daytime can be increase by injecting solar PV into a grid. There is a Balaju industrial area if power generation from solar PV exceed the local demand, then this excess power can be supply to industrial sector by installing the suitable rating of capacitor for maintaining reactive power demand of the industry.

Figure 3.2 Satellite view of Tarakeshwor municipality

Tarakeshwor is a municipality in Kathmandu District in Bagmati Pradesh of Nepal that was established on 2 December 2014 by merging the former Village development committees Dharmasthali, Futung, Goldhunga, Jitpurphedi, Kavresthali, Manmaiju and Sangla. It has total area of 34.9 km^2, according to census 2011 there are 81,443 population. Having coordinate of 27°47′12″N 85°18′11″E. According to NEA, total number of consumers fed by Balaju distribution feeder are 29,879. Consumers in different categories are listed in Table 3.1

Table 3.1 Different type consumer and their number at Balaju DCS

S.N.	Type of Consumer	Number
1.	Commercial	237
2.	Domestic	29,055
3.	Entertainment	2
4.	Industrial	335
5.	Internal Consumption	4
6.	Irrigation	4
7.	Non-Commercial	102

S.N.	Type of Consumer	Number
8.	Non-Domestic	40
9.	Religious and Cultural	31
10.	Streetlight	9
11.	Temp. Supply	13
12.	TOD Industrial	29
13.	Water Supply	18
	Total	29,879

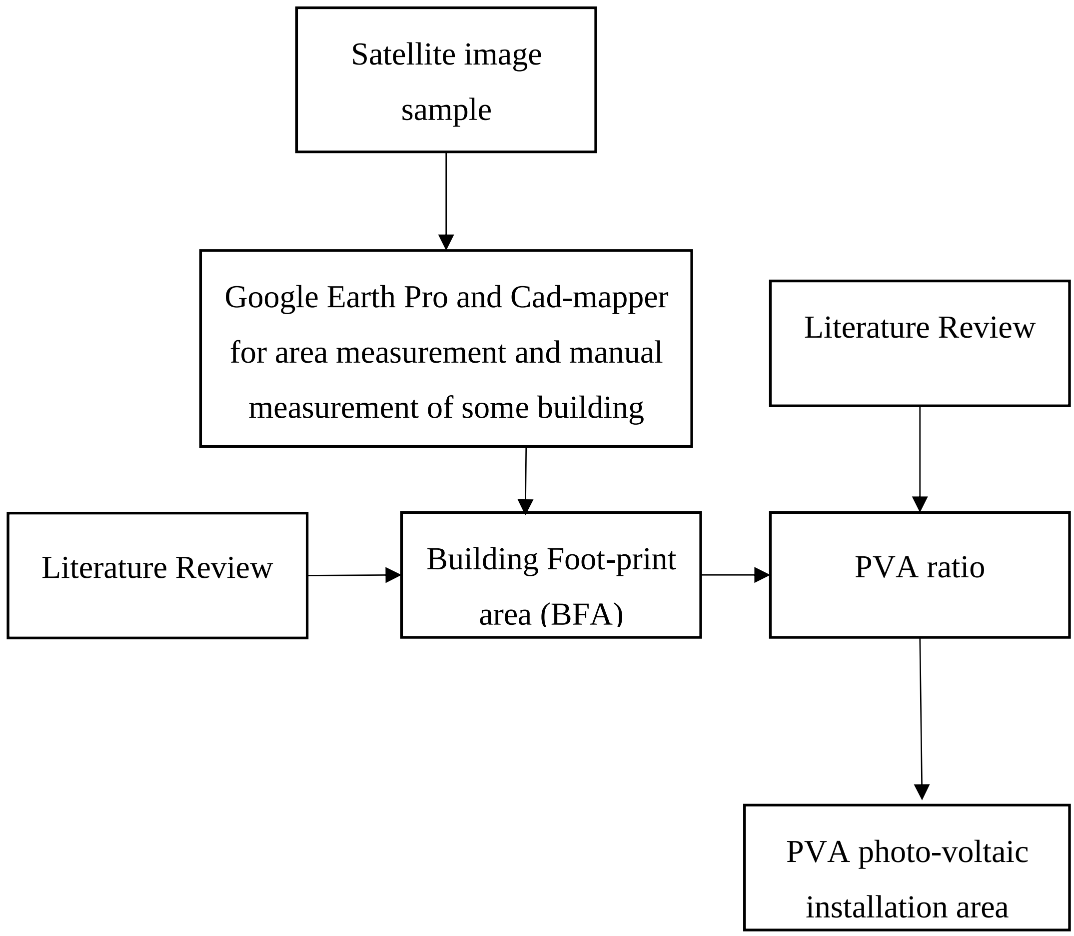
Among theme only 11 commercial and large-scale building of Bishnumati feeder is taken for entire research.

3.2 Potential area determination

In any solar photovoltaic system area is the major requirement, larger the area higher will be the generated power. Also, efficiency is governing factor for its power output up to now monocrystalline solar cells have high efficiency with slightly higher cost. This study mainly focusses on solar power generation from selected building from their roof-top due to which area is the constraint factor so higher efficiency monocrystalline solar cell is used. For selecting of buildings cluster sampling is used. In this method entire feeder is divided into eleven cluster and load centre is find out. The nearby large building from load centre is used for solar PV installation. The output of the solar cell also depends on environmental factors like as temperature, irradiance, environmental pollution, shading etc, they can be analysed after installation. This research work mainly focused on solar power generation based on available roof-top area of selected building and its performance with national grid. The methodology used for area determination is from (Singh and Banerjee, 20150). The area determination block diagram is shown Figure 3.3.

For actual area calculation, satellite images from google earth pro is taken and its area is measured. For the validation of area measure by google earth pro, cad-mapper software is used, it measures the area by converting the area map to AutoCAD. For further validation, random sampling is used and among eleven buildings area of three building measure manually. The area measured by google earth pro, cad-mapper is a Building Foot-print Area (BFA) which is multiplied by PVA ratio to obtain actual PV installation area.

For PVA ratio different literatures are referred and select the value 0.47 for Asian region.



(Singh and Banerjee, 20150)

Figure 3.3 Block diagram for area determination

For entire analysis eleven commercial and large-scale building are selected as shown in Table 3.2

Table 3.2 Name of buildings for solar PV installation

S.N.	Name of Building	Remarks
1.	Himalayan City Centre	Commercial
2.	Bhatbhateni Supermarket	Commercial
3.	Buddha Mall	Commercial
4.	Ganja Hall	Commercial
5.	Aastha Narayan Pictures Pvt. Ltd.	Commercial

S.N.	Name of Building	Remarks
6.	Janamaitri Hospital	Hospital
7.	Kathmandu Upatyaka Khanepani Limited	Service oriented
8.	Nepal Bureau of Standard	Service oriented
9.	Lotse Mall	Commercial
10.	World Link Communication	Commercial
11.	Krishi Farm	Agriculture

To measure the building foot-print area that means building roof-top area Google earth pro is used. For further validation of area calculated by google earth pro, Cad-mapper is used. Through cad-mapper, area map is converted to AutoCAD file and hence area is determined from AutoCAD. Average of area measured by google earth pro and cad-mapper is used for further analysis. The sample area calculation of Himalayan city centre through google earth pro is shown in Figure 3.4.

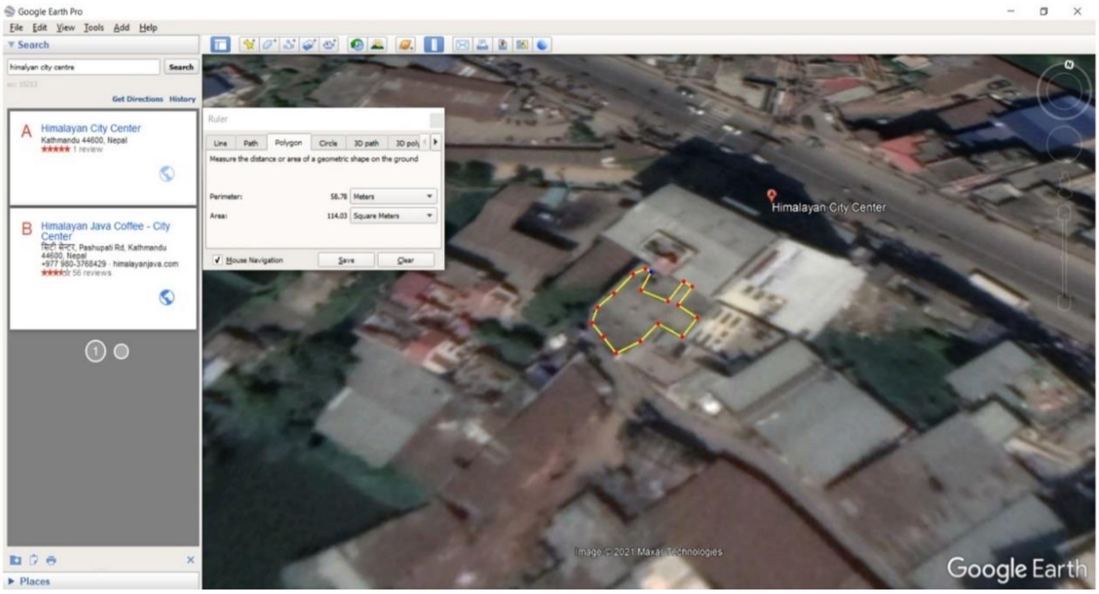


Figure 3.4 Foot-print area calculation through google earth pro

3.3.1 PVA ratio

The area measured by the google earth pro and cad-mapper is the building foot-print area which is not use fully for PV installation. Due to different structure in building, shading due to nearby building and shading due to PV-module itself foot-print area is not totally utilized, and hence photovoltaic installation area need to be determined. For this a term PVA ratio (Photo-voltaic area ratio) is introduced, which when multiply by building foot-print area give the photo-voltaic area. Different literatures are preferred for determination of PVA ratio and taken as 0.47 (Singh and Banerjee, 2015, Ordonez et al, 2010, Mantavon et al, 2004) for this work. The process of calculation of photo-voltaic area is shown in Figure 3.5.

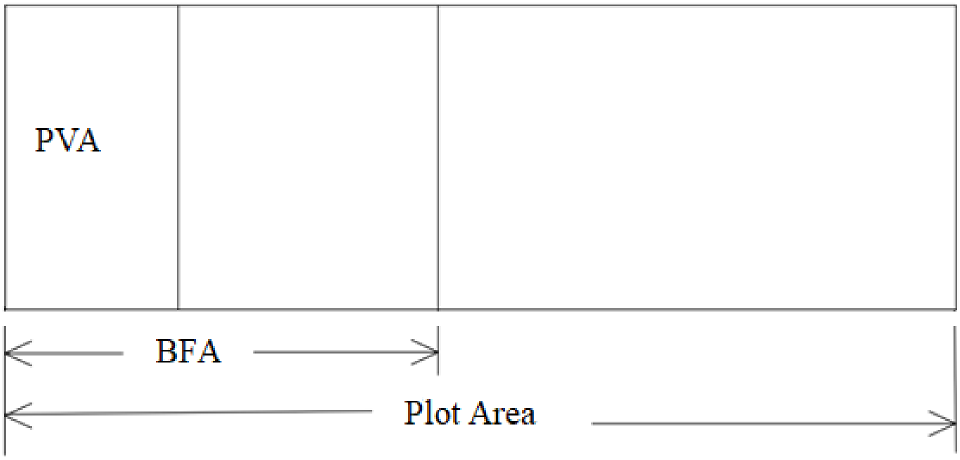


Figure 3.5 Correlation between Built in area, BFA and PVA

The final area that is photo-voltaic area is used for solar power generation that means for installation of solar photo-voltaic module. The sample of installation of solar array in Himalayan City Centre is shown in Figure 3.6.

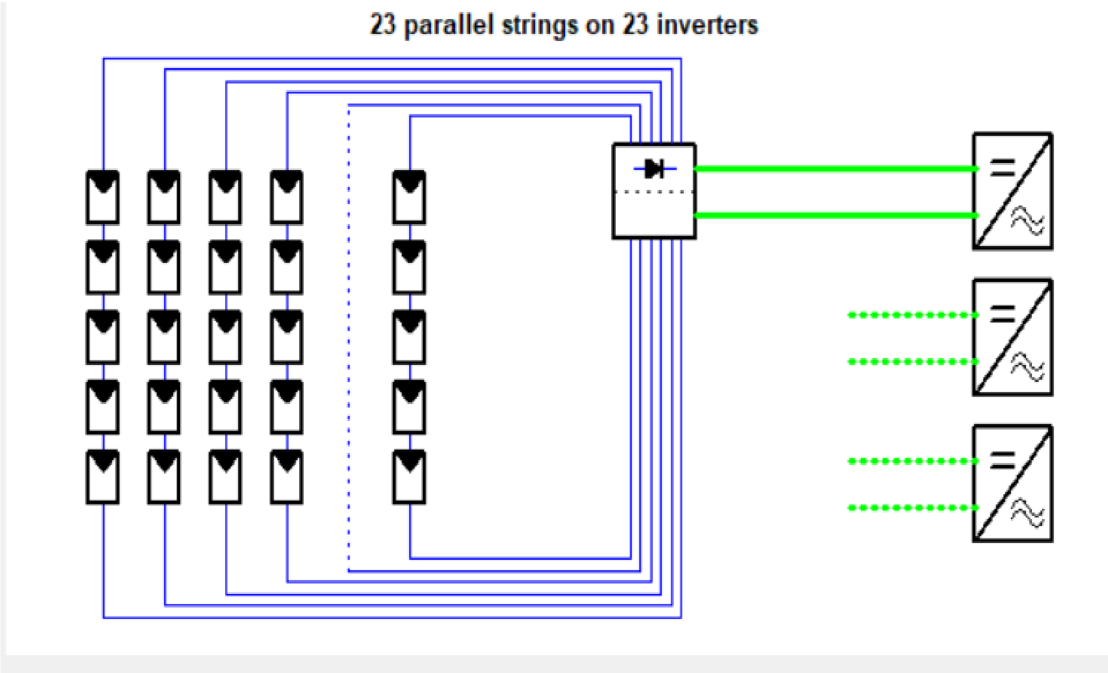


Figure 3.6 Sample solar array installation on Himalayan City Centre

ET solar of each module 255 W_P is used. From available area total of 115 module are arranged in the form of array. Among theme five module are connected in series and such a twenty-three system are connected in the parallel in the form of string as shown in Figure 3.6. Each solar module has maximum power point voltage (V_{MP}) is equal to 26 V and open circuit voltage (V_{OC}) is 42.1 V. The total system voltage at operating condition is 130 V and current is 193 A. for this system total of 23 inverters (Model UNO-DM-1.2-TL-PLUS, manufacture by ABB) are used with input voltage range of 90 to 580 V. Each inverter has rated at 28 KW_{AC}. Similar type of installation is used in rest of the buildings.

3.3 Energy generation and performance analysis

From available PVA, the power and hence energy generation and performance parameter are determined through PVsyst Software. The overall block diagram for performance analysis is shown in Figure 3.7. PVsyst is used for this entire analysis. PVsyst is the globally used tools for designing and analysing solar PV system. After providing the geographical condition like as latitude, longitude, altitude, time zone etc it automatically extract the required data like as irradiance, temperature and other required parameter and provide the report accordingly. For this study monocrystalline solar module is used due to its high efficiency as compared to polycrystalline solar module.

Fixed plane tilt with plane tilt of 27^o with south facing is used. Solar array with number of modules in series and parallel is designed for each building for maximum power output. The shading phenomena is considered during determination of PVA so in PVsyst shading effect is not considered. Different loss factor like as soiling loss, loss due to series diode, thermal loss, ageing loss etc are defined, after collecting the data from literature. From these provided input data PVsyst gives output generation capacity and different performance parameters. The input parameter required for the PVsyst for sample calculation at Himalayan City Centre is listed in Table 3.3

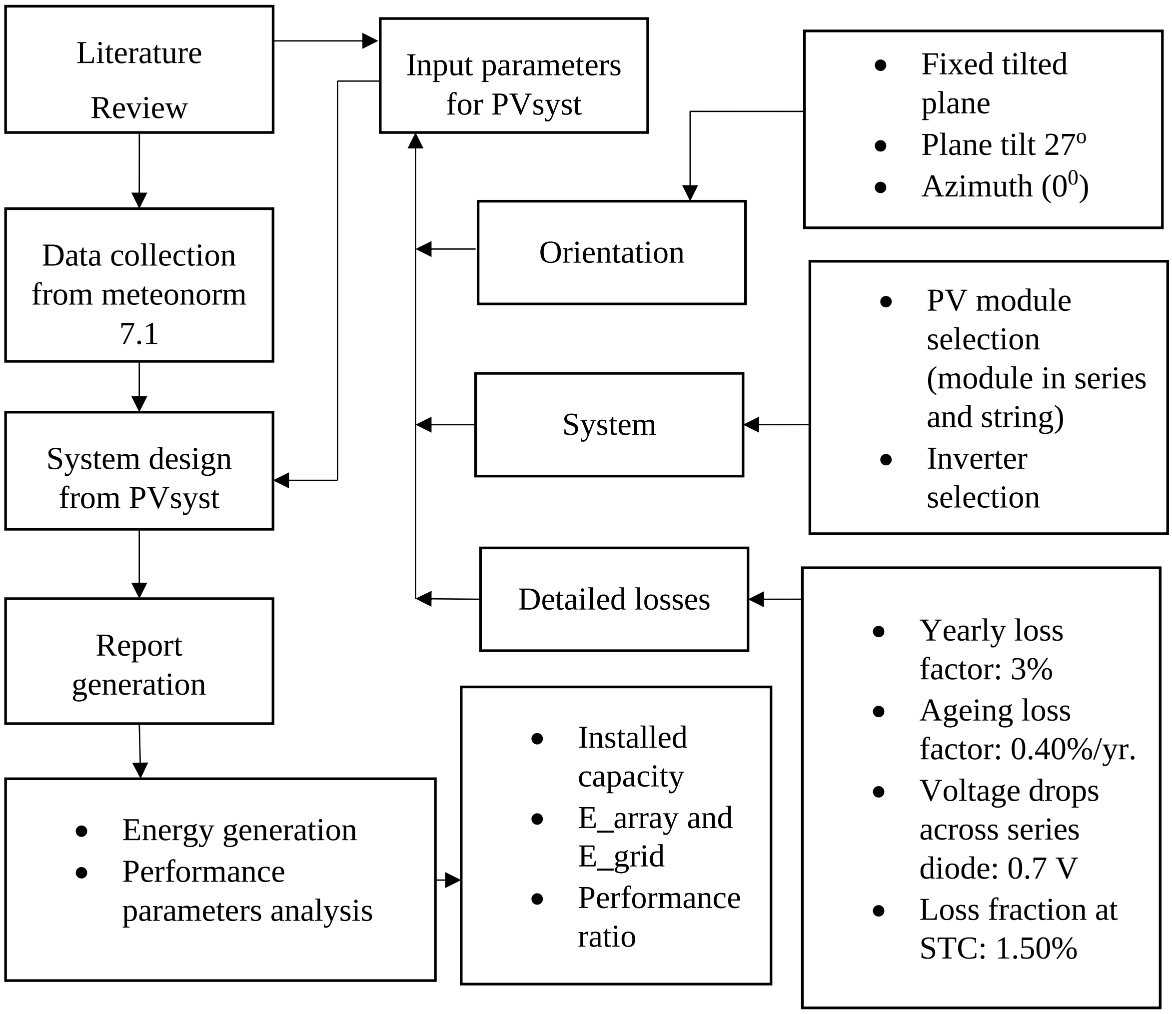


Figure 3.7 Block diagram for installed capacity determination and performance analysis

Table 3.3 Input Parameter for PVsyst (Himalayan City Centre)

S.N.	Parameters	Values
	Meteo database/ Geographical Sites	
1.	Site Name	Himalayan City Centre
2.	Region	Asia
3.	Country	Nepal
4.	Latitude	27.74 N
5.	Longitude	85.30 E
6.	Altitude	1304m
7.	Time Zone	5.45

S.N.	Parameters	Values
Orientation		
1.	Plane tilt	27
2.	Azimuth	0.20
System		
2.	Solar module, rating, and units	Sun-power/280Wp/104
3.	Arrangement	13 strings of 8 panels
4.	Inverter and rating	ABB/2 KWac
Array losses		
1.	Array soiling losses	3%

The other require input parameter and simulated result is shown in appendix A, and actual energy generated by the Himalayan city centre is calculated through PVsyst. Similar procedure is used to find out the actual energy generated by different building and performance ratio.

3.4 ETAP modelling

Electrical Transient Analyzer Program (ETAP) is an electrical network modelling and simulation software tool, used by power systems engineers to analyse electrical power system dynamics, transients, and protection. The overall block diagram for ETAP modelling is shown in Figure 3.8.

The required parameter for ETAP is obtain from QGIS file. QGIS file is prepared by loss reduction department of NEA, so in this analysis secondary data are utilized. Some of the new points which are not shown in QGIS file as prepared by NEA is added in QGIS.

The major parameter taken from GIS are length of transmission line between different buses of Bishnumati feeder, type of conductor used, transformer rating and loading. The GIS file of Bishnumati Feeder is shown in Figure 3.9. GIS map show the location of transformer, their rating, length of transmission line, length of different section and type of conductor used. Due to the unclarity in figure, only distribution line section represented by line and location of distribution transformer represented by node is shown in Figure 3.9. Conductor library is inserted in ETAP software, after inserting distribution feeder length and type of conductor, it automatically calculates the line parameters. Nepal Electricity Authority (NEA's) lux sheet is used to calculate the actual loading condition.

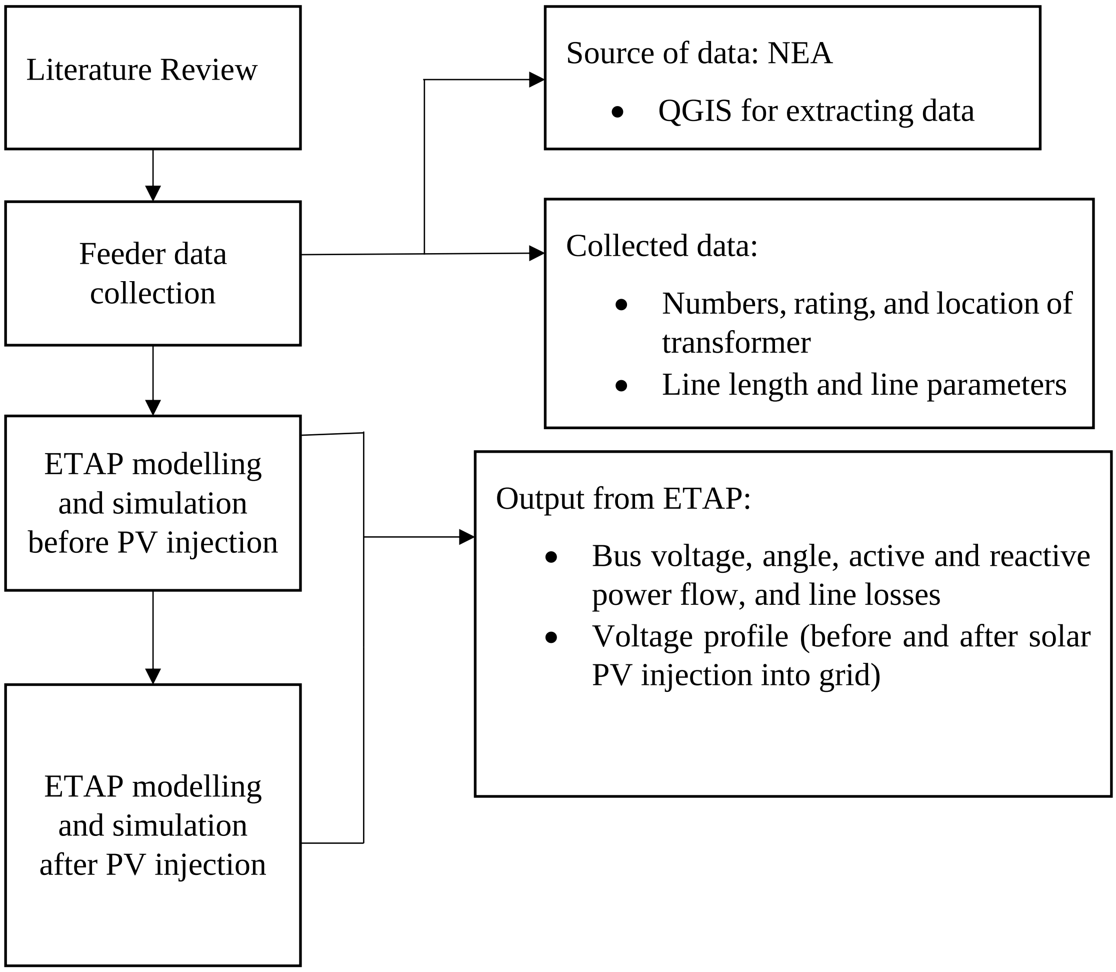


Figure 3.8 Block diagram for ETAP simulation

For load flow analysis in ETAP, Balaju substation is taken as power grid. Power grid supply as much as power demand by the load. Except Balaju substation rest of the buses are taken as load bus. When power generated from solar system is injected into grid, it is supply to local load so, energy demand from power grid is decreases. At constant voltage level if power delivered from power grid decreases, it gives rise to low line losses and hence increase the efficiency of the system.

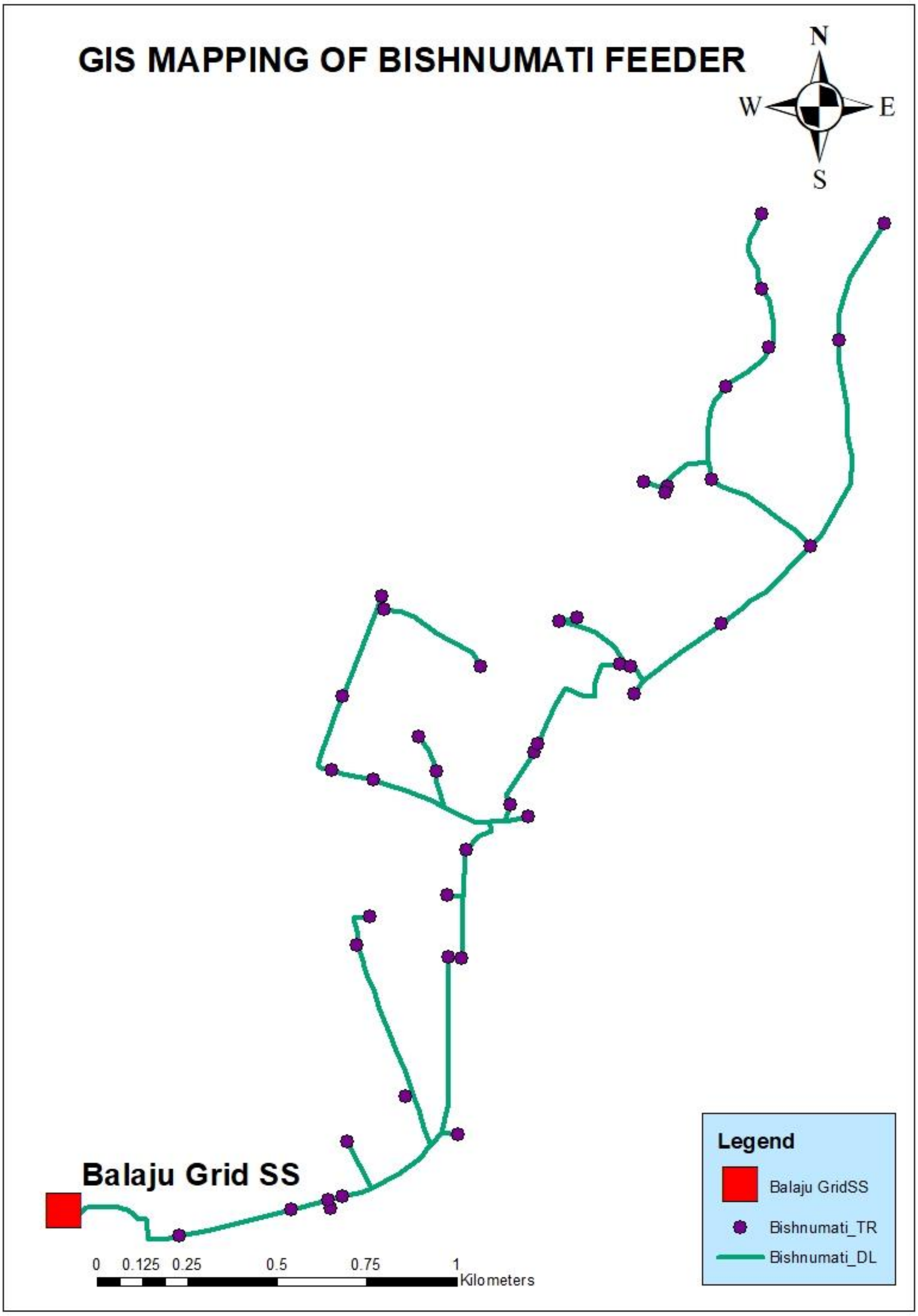


Figure 3.9 GIS of Bishnumati Feeder

The different input parameter used for load flow analysis in ETAP for load calculation is shown in Table 3.4.

Table 3.4 Input parameter for load calculation in Bishnumati Feeder

PLACE	Tr. (kVA)	HV (kV)	LV (V)	I_R (A)	I_Y (A)	I_B (A)	% Loading
Balaju Chowk	200	11	0.4	236	194	238	77.13
Banasthali Chowk	200	11	0.4	150	232	232	70.90
Basantanager	200	11	0.4	170	154	176	57.73
Bypass Chowk	200	11	0.4	184	180	218	67.20
Dip Jyoti School Ground	200	11	0.4	130	230	204	65.12
Gumba Chauki	100	11	0.4	84	71	109	60.97
Gumba Chauki Ii	200	11	0.4	158	158	142	52.88
Hiledole Height	100	11	0.4	74	72	71	50.11
Infront 24 Ghante Hospital	200	11	0.4	174	188	206	65.58
Infront Abhiyan School	100	11	0.4	61	76	80	50.11
Infront Balaju Police	100	11	0.4	62	90	108	60.04
Infront Bid Gate	200	11	0.4	152	204	126	55.65
Kukl Manamaiju	50	11	0.4	36	38.5	34.5	50.34
Kumaristhan I	200	11	0.4	148	136	170	52.42
Kumaristhan II	200	11	0.4	164	156	216	61.89
Loktantric Chowk	200	11	0.4	136	226	194	64.20
Machhapokhari Chowk	100	11	0.4	70	108	64	55.88
Manamaiju	100	11	0.4	73	109	105	66.28
Manamaiju Chantyal Sang	300	11	0.4	330	285	357	74.82
Manamaiju Ghale Ko Pul	100	11	0.4	79	64	78	51.03
Manamaiju Indrayani Pul	200	11	0.4	220	168	158	63.04
Manamaiju Mauripalan	200	11	0.4	120	232	224	66.51
Near Bhatbhateni	100	11	0.4	85	92	111	70.20
Near Mansing School	200	11	0.4	236	198	146	66.97
Near Nabil Bank	100	11	0.4	60	89	108	59.35
Near Purnima Hotel	200	11	0.4	140	230	160	61.20
Near Puspa Dairy	200	11	0.4	186	180	128	57.04
Near Subhakamana School	300	11	0.4	252	348	198	61.43

PLACE	Tr. (kVA)	HV (kV)	LV (V)	I_R (A)	I_Y (A)	I_B (A)	% Load ing
Near Tarun School	300	11	0.4	336	279	324	72.28
Nepaltar Chowk	300	11	0.4	252	231	207	53.11
Nepaltar Pul Wari	200	11	0.4	230	200	214	74.36
Opposite Tarkari Bazar	200	11	0.4	230	122	210	64.89
Opposite To Battery Factory	100	11	0.4	91	72	61	51.73
Opposite To Ganga Hall	300	11	0.4	282	267	195	57.27

The major input parameter are name of transformer and their rating, current following through the different phases. Colum first of Table 3.4 show the name of places i.e., name of different buses. Second Colum show the rating of transformer, third Colum show the voltage rating of High Voltage (HV) side of transformer in kV, fourth Colum show the Low Voltage (LV) rating of transformer in V, Colum fifth to seventh show the current in phases R, Y and B in LV side in ampere. All these data are collected from loss reduction department under NEA. The last Colum of Table 3.4 show the percentage loading of transformer. The overall ETAP simulation without solar photovoltaic penetration is shown in Figure C.1 to C.4 at APPENDIX C.

The general system description during load flow analysis is shown in Table 3.5

Table 3.5 General system description on load flow analysis before solar PV injection

Study ID	Bishnumati
Study Case ID	LF
Data Revision	Base
Configuration	Normal
Loading Cat	Design
Generation Cat	Design
Buses	57
Branches	56
Generators	0
Power Grids	1
Loads	46

Study ID	Bishnumati
Load-MW	5.426
Load-MVAR	2.628
Generation-MW	5.596
Generation-MVAR	2.988
Loss-MW	0.17
Loss-MVAR	0.36
Mismatch-MW	0
Mismatch-MVAR	0

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Site selection for solar photo-voltaic installation

As discuss in methodology section, Bishnumati feeder of Tarakeshwor municipality is chosen for solar photo-voltaic installation in large scale building. Bishnumati feeder is supplied by the Balaju substation. The single line diagram (SLD) of Bishnumati feeder with solar photo-voltaic installation location is shown in Figure 4.1 and Figure 4.2.

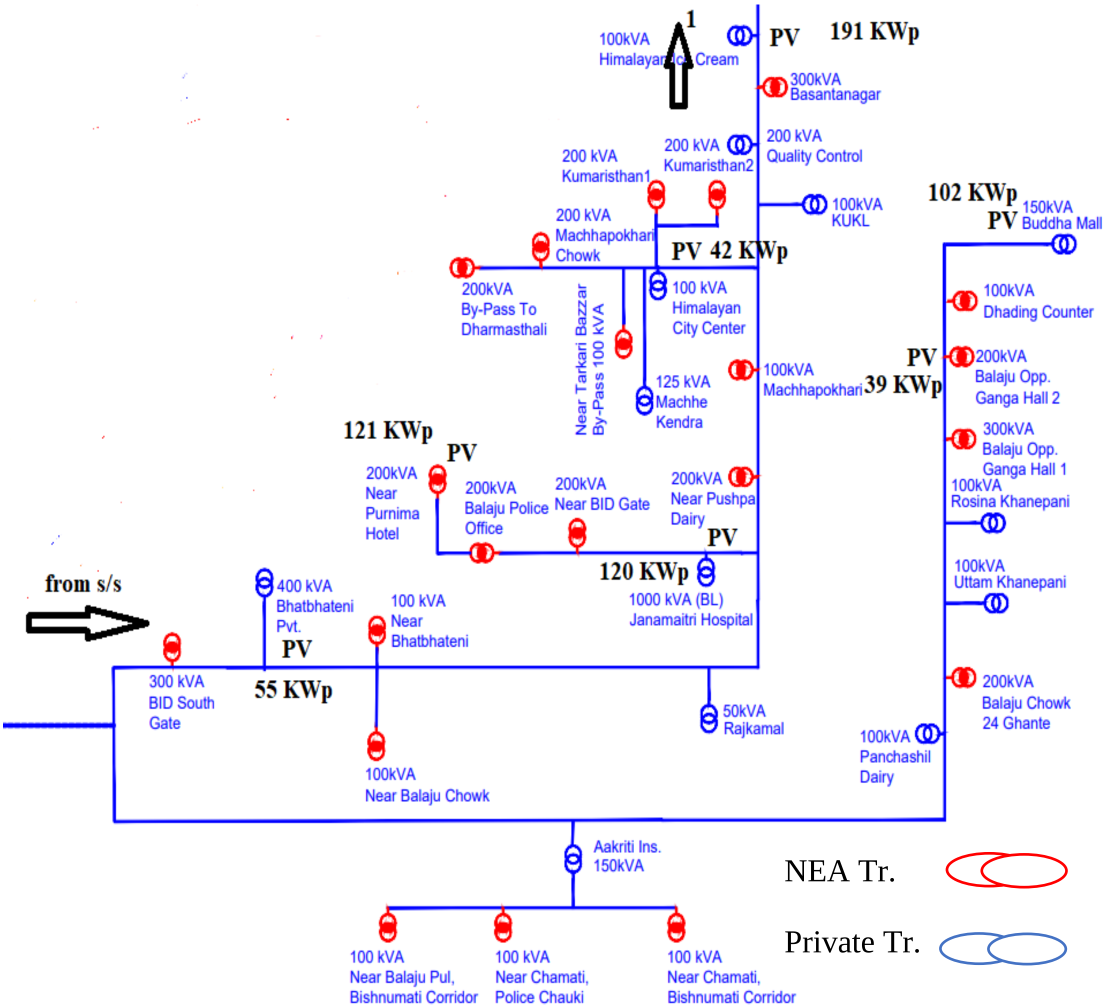


Figure 4.1 SLD (1) of Bishnumati feeder and point showing PV installation area

Balaju substation is taken as source for Bishnumati feeder as shown in Figure 4.1 and Figure 4.2. the area where photo-voltaic power is penetrated is shown by term PV in single line diagram. Half part of SLD is shown in Figure 4.1 and remaining section is shown in Figure 4.2. total of eleven potential building is selected for installation of solar photo-voltaic module. Area of selected building is measured to find out the actual solar photo-voltaic installation area (PVA).

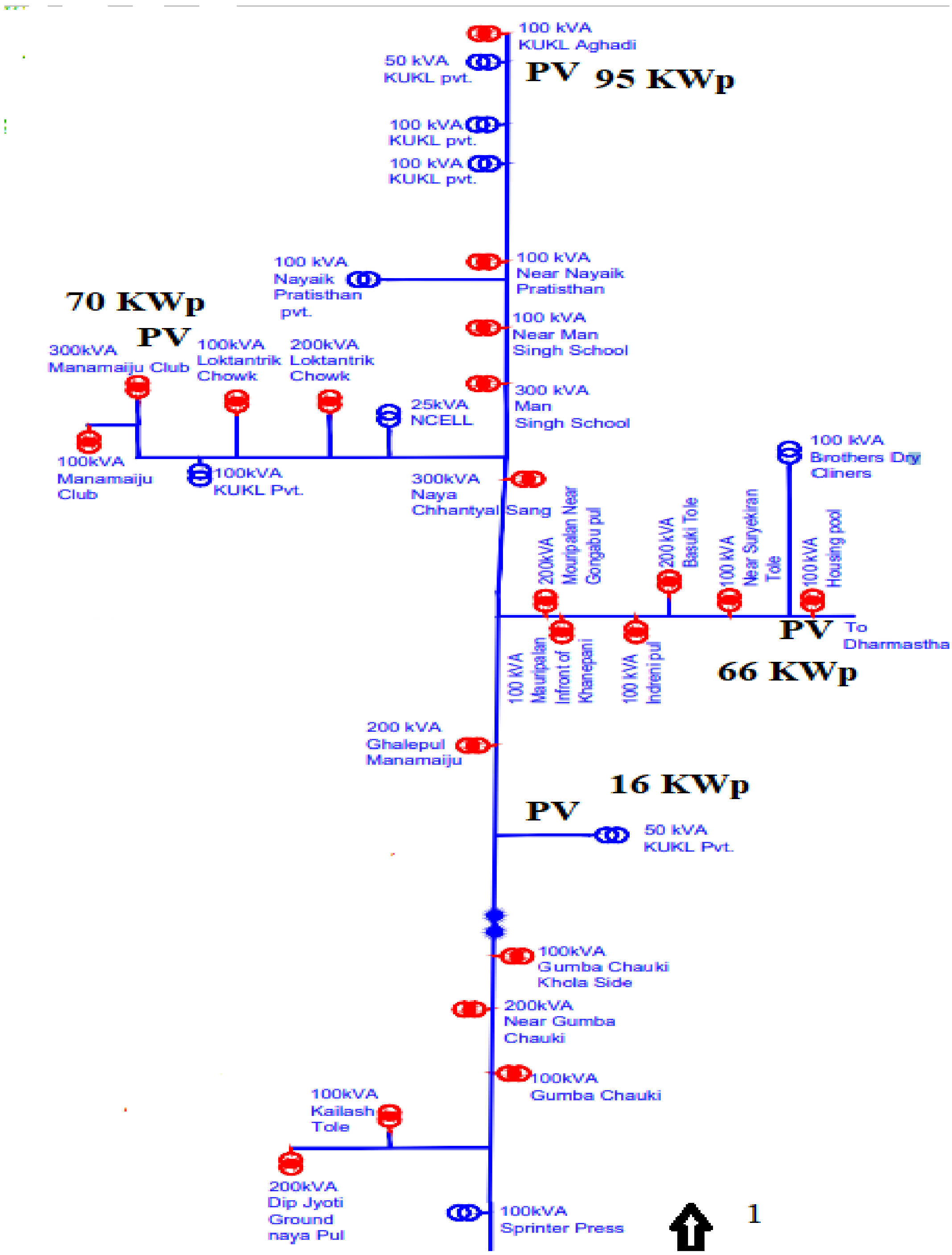


Figure 4.2 SLD (2) of Bishnumati feeder and point showing PV installation area

4.2 Potential area determination

Potential area of selected buildings is determined by applying the methodology as discussed in chapter three. The building foot-print area (BFA) is multiplied by PVA ratio to find out the photo-voltaic installation area (PVA). PVA ratio is taken as 0.47

(Singh and Banerjee, 2015). The measure building foot-print area and PVA after applying PVA ratio is shown in Table A.1 at APPENDIX A

From Table A.1 at APPENDIX A, the total available photo-voltaic area is 4,190.11m^2, which can be used for solar module installation purpose. The graphical representation of PVA of selected building is shown in Figure 4.3.

Among the consider building, from Figure 4.3, Lotse Mall has maximum photo-voltaic area and Kathmandu Upatyaka Khanepani Limited has lowest photo-voltaic installation area. Due to the availability of high PVA of Lotse Mall able to generate maximum solar power, because for given type of solar module, output power is depended on area of the installation. Similarly, Kathmandu Upatyaka Khanepani Limited has low PVA and hence it has low install capacity.

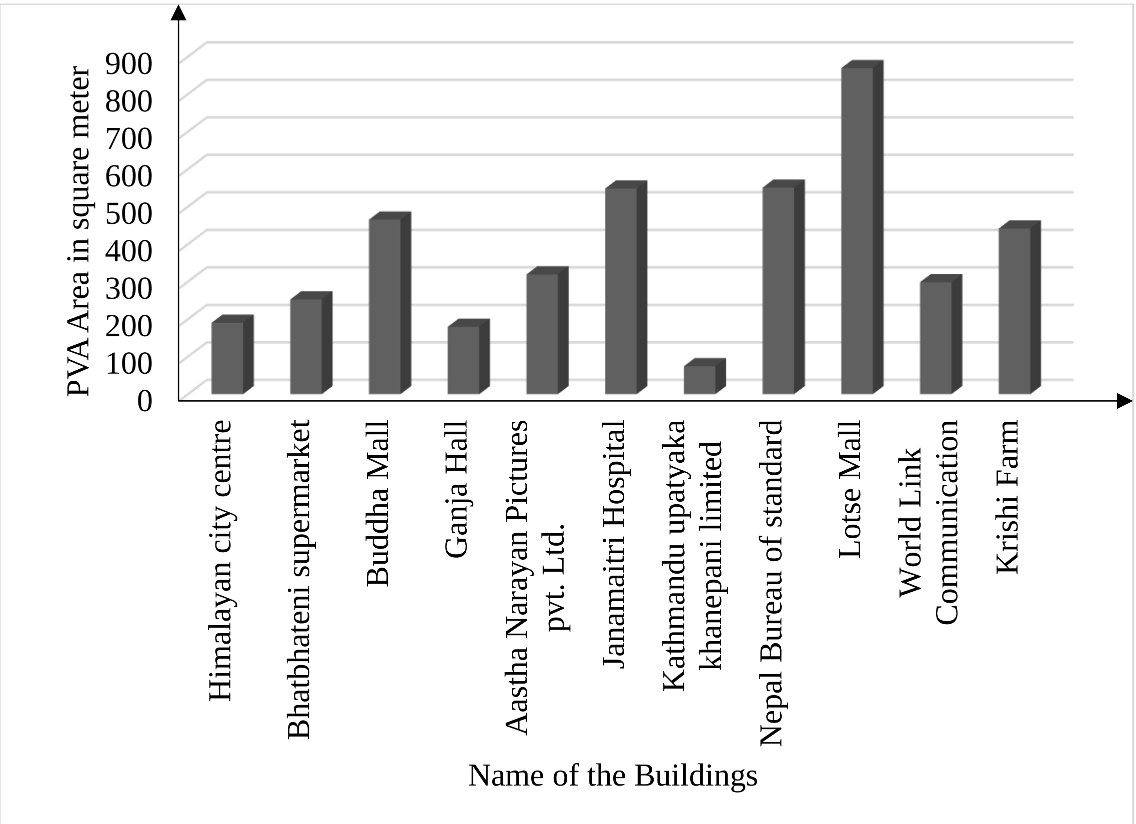


Figure 4.3 PVA of Selected Buildings

4.3 Energy generation and performance analysis

The energy generation and performance analysis are done through PVsyst software and it's major outcome of Himalayan city centre is shown in Table A.2 at APPENDIX A. the major parameters are ambient temperature (T_amb), effective irradiance in

KWh/m^2, energy output through array (E_Array), energy supplied to grid (E_grid) and performance ratio (PR). The effective global irradiance, energy generated by array, energy supplied to grid and ambient temperature is shown from Figure 4.4 to 4.5.

Figure 4.4 show the monthly irradiance at Himalayan city centre. From Figure 4.4, maximum irradiance about 185 kWh/m^2 is obtain in the month of December and minimum of about 130 kWh/m^2 is obtain in the month of July. This result can be used for reference study of Kathmandu valley and from here it is clear that maximum power that solar PV generate at the December and minimum power in July. So, during load dispatch scheduling should be done accordingly. The actual power generated by solar PV which is also called as DC power is always greater than AC power injected into the grid. There is certain power loss during conversion from DC power as generated by solar module to AC, through inverter and losses in cable which are used to inject the power in the grid. Figure 4.5 show the actual energy generated by module and energy injected into a grid by Himalayan city centre.

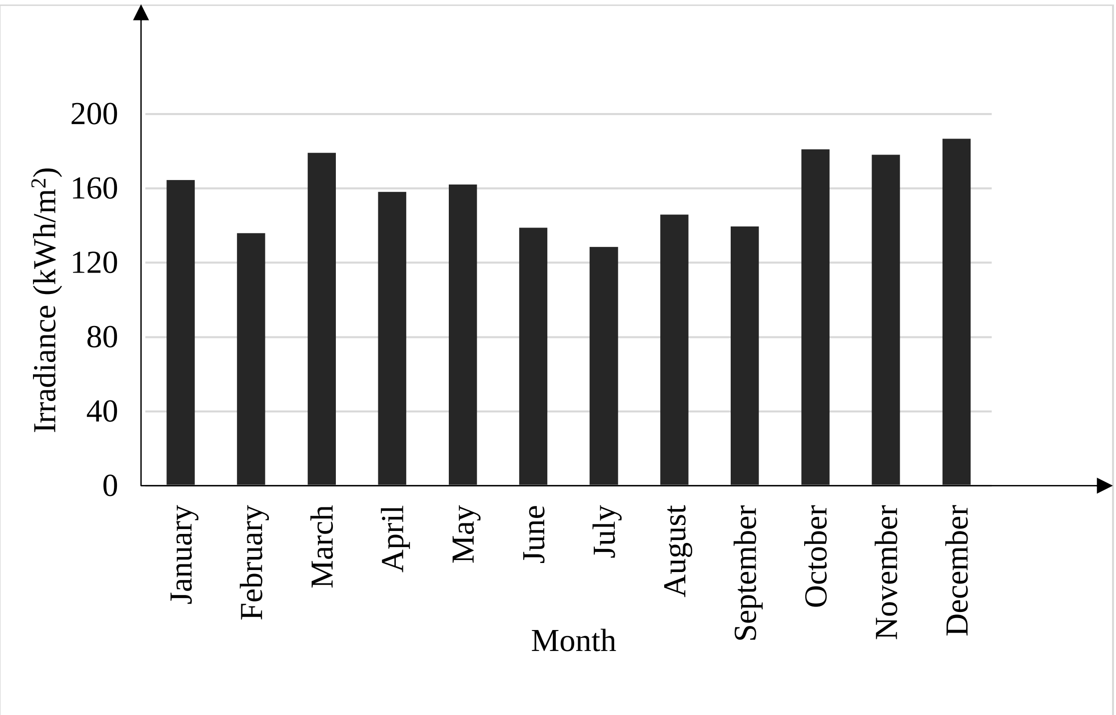


Figure 4.4 Monthly irradiance at Himalayan City Centre

Due to higher irradiance available during month of December high energy is generated similarly due to lower irradiance in the month of July, energy generated at that month is also low.

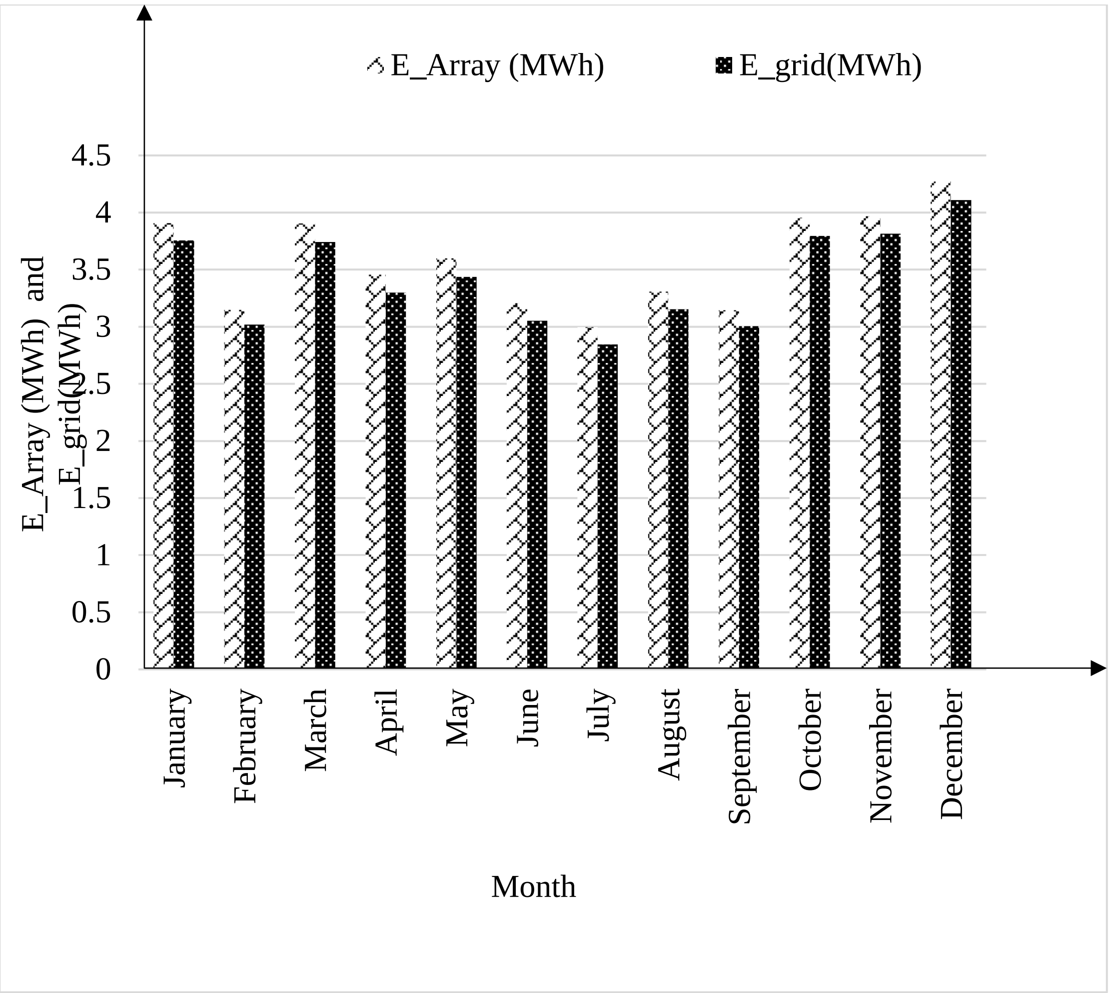


Figure 4.5 Energy generated, and the solar array and energy supplied throughout the year by Himalayan City Centre

In solar cell the relationship between temperature and current is directly proportional, i.e., if the temperature increases the output current is high. But the relationship of voltage and temperature highly inversely proportional due to which increase in temperature give rise to very low voltage.

The power of solar cell is the product of current and voltage and due to high reduction in voltage with increase in temperature the output power and hence energy generated by solar module reduced drastically. From Figure 4.6, the temperature is maximum at the month of June-July, and power generation is low. Similarly, the ambient temperature is low about 10^{o}C in the month of December, due to low temperature current is slightly decrease but voltage is high, due to which power and hence energy generated is high during month of December.

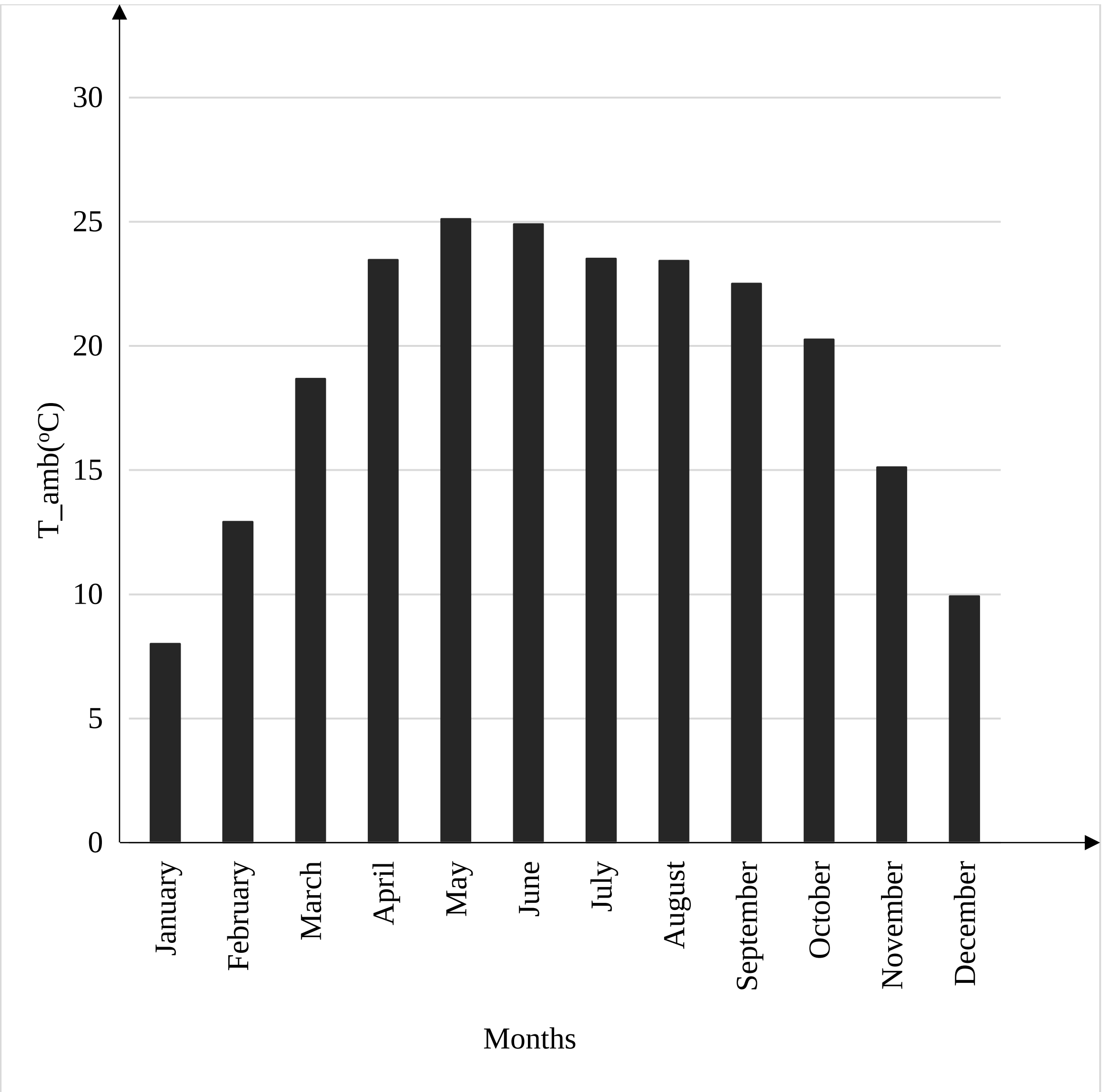


Figure 4.6 Monthly temperature variation at Himalayan City Centre

In solar photo-voltaic system design, performance ratio should be greater than 0.7 (Singh and Banerjee, 2015: Chajyant et al., 2009) is consider better, at Himalayan city centre except month of march, April and May the performance ratio be greater than 0.7. The performance ratio of solar PV installation at the month of January and December is maximum having value of 0.77.

Performance ratio mainly depend on environmental conditions like as irradiance level, temperature, dust particle in air (i.e., quality of air), etc. Also, the average performance ratio over the year is greater than 0.7 so the result is satisfactory.

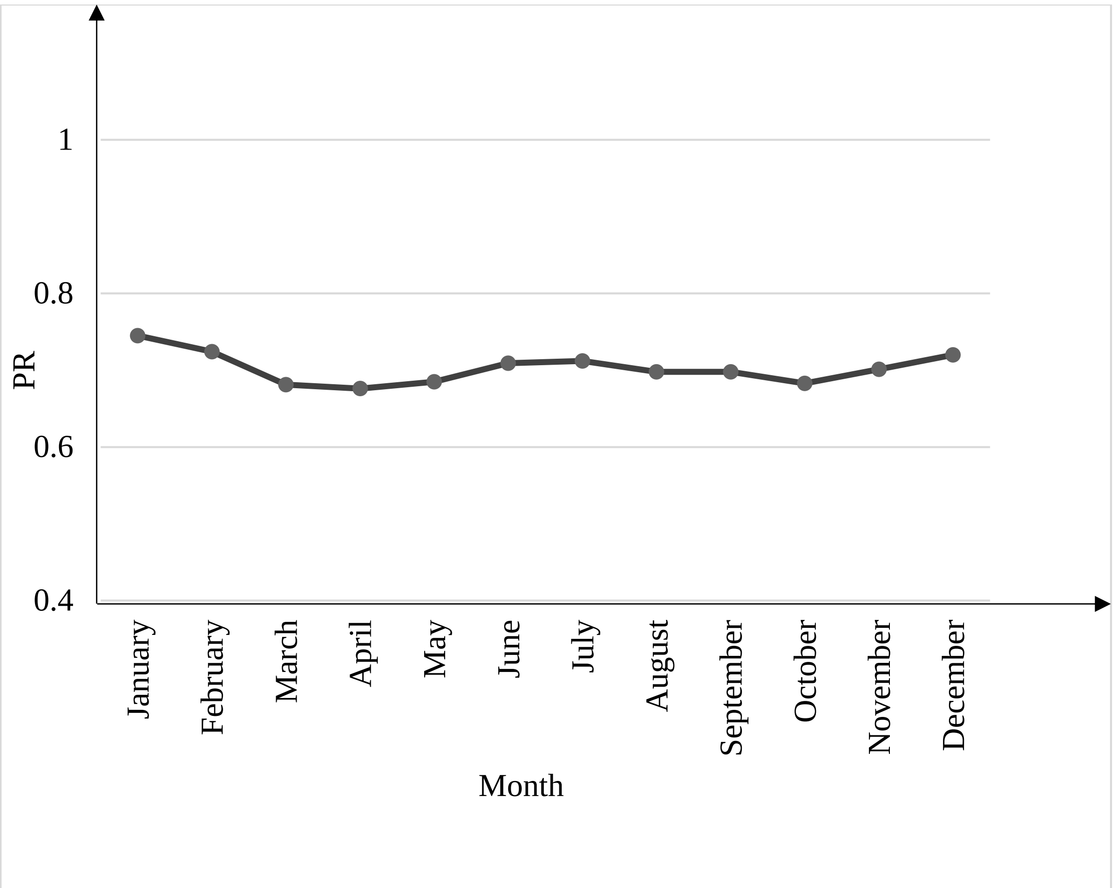


Figure 4.7 Monthly performance ration at Himalayan City Centre

In similar manner, yearly average generation and performance parameter of all building are analysed and listed in Table A.3 at APPENDIX A.

Graphically energy generated by solar panel, energy supply to grid and performance ratio of different building is shown in Figure 4.8 and 4.7.

From figure 4.6, Lotse Mall has greater foot-print area and hence larger photovoltaic area so that energy generated by Lotse Mall is also large as compared to other buildings available. There is a certain different between energy generate by solar array and actual energy injected into the grid due to the losses in the system.

Performance ratio shows that how actually solar module can perform i.e., it is the ratio of measure output to expected output, greater the value of PR higher will be the efficiency of the system. The overall performance ratio of selected potential building is 0.74.

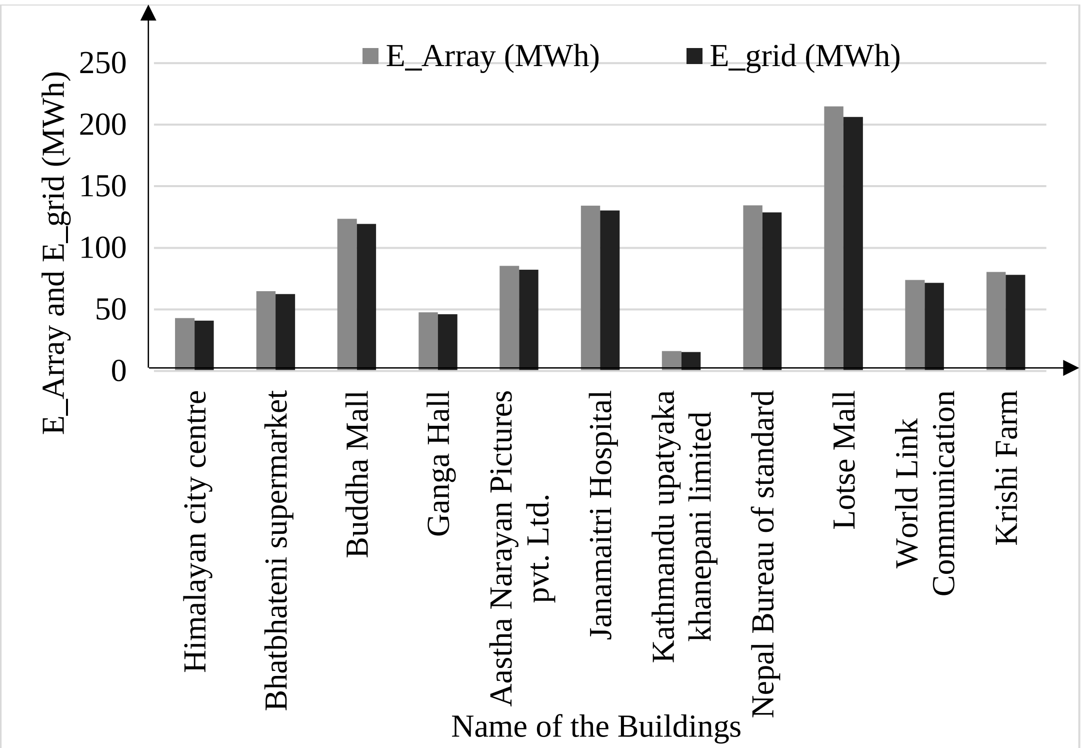


Figure 4.8 Yearly energy generation by array and energy supplied to grid

If performance ratio is greater than 0.7 it is satisfactory (Chaiyant et al, 2009). Figure 4.9 show that all the building selected have the performance ratio greater than 0.7. the maximum performance ratio is 0.79 at Ganga Hall and minimum is 0.7 at Himalayan City Centre.

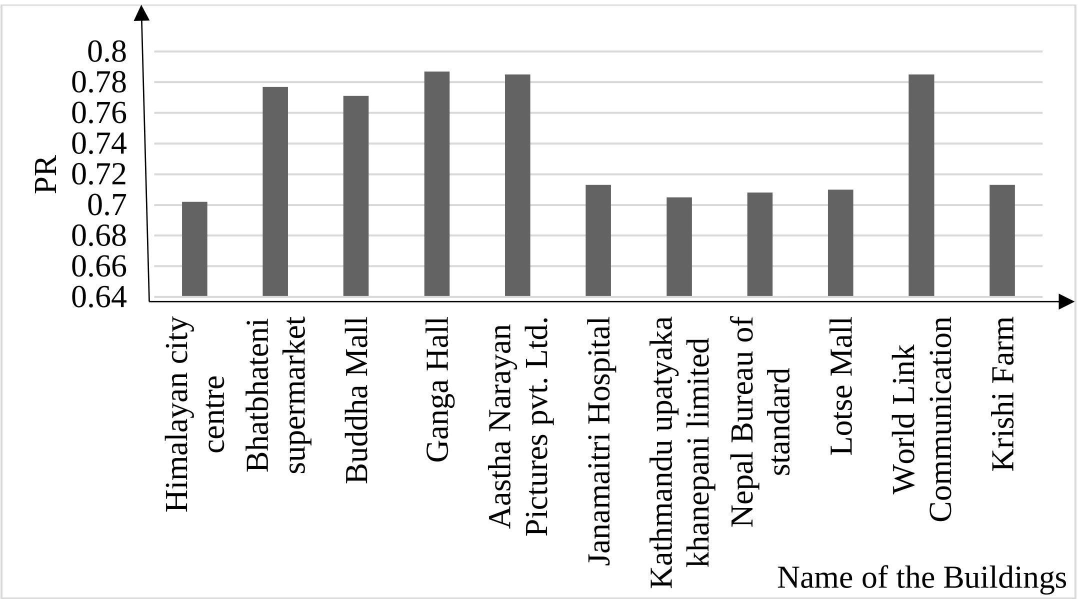


Figure 4.9 Yearly Performance ratio off different buildings

The   report generated from PVsyst is shown in APPENDIX B.

4.4 Capacity Factor

Capacity Factor (CF) is the ratio of actual energy generated by solar system during specific period of time to the actual energy that can be generated by solar system during this time period at rated power (Kymakis et al., 2009: Sharma and Chandel, 2013: Singh and Banerjee, 2015). Higher capacity factor means the plant run at maximum output for long time and more economical is the plant. Capacity factor is different for different power plant like solar, wind, thermal, hydro etc. the solar PV system has the capacity factor ranges from 10 to 30 %. The capacity factor of eleven selected building is shown in Figure 4.10.

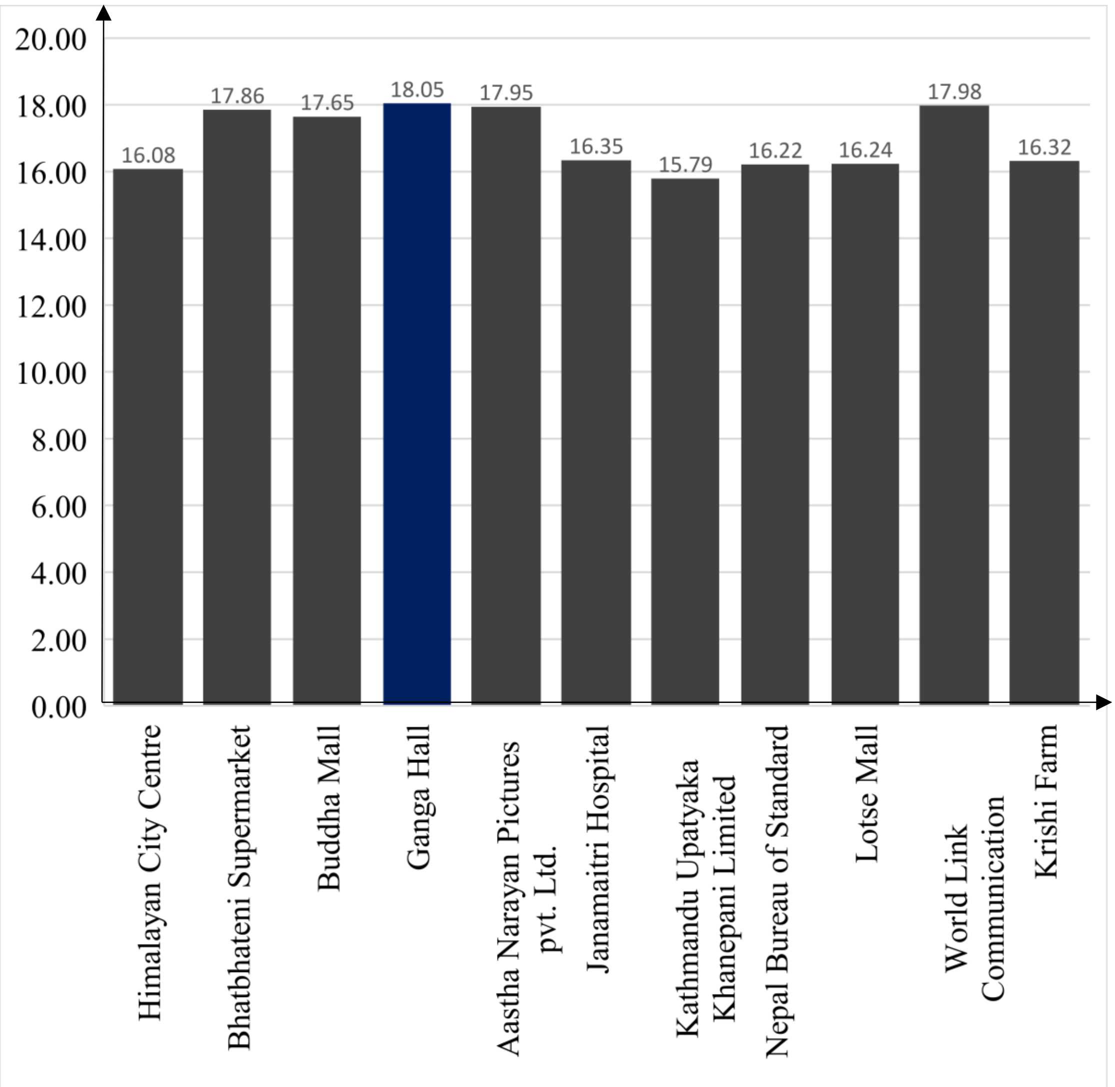


Figure 4.10 Capacity factor of solar PV at different buildings

The maximum capacity factor is 18% at Ganga Hall and World Link Communication and minimum of 15.79 % at KUKL with average capacity factor of 17 %.

4.5 ETAP Simulation of Bishnumati feeder

For entire modelling and simulation of Bishnumati feeder ETAP is used. For finding out the deviation on voltage profile and line losses, analysis is done before and after solar PV injected in the grid.

4.5.1 Before solar PV injection into grid

During entire simulation, the voltage at different buses is calculated. Active and reactive power flow, line losses, bus angle in various buses is checked. The major parameter is voltage at different buses. Among 57 buses, Balaju substation is taken as slack bus and other are PQ bus. The load flow analysis and their bus voltage, conductor type and length is shown in Figure C.1 to C.7 at Appendix C.

From 57 buses 9 buses are taken for construction of voltage profile. For this some buses are taken near to substation, some from middle section of Bishnumati feeder and some are taken from far end of the Bishnumati feeder to construct the voltage profile as shown in Figure 4.11.

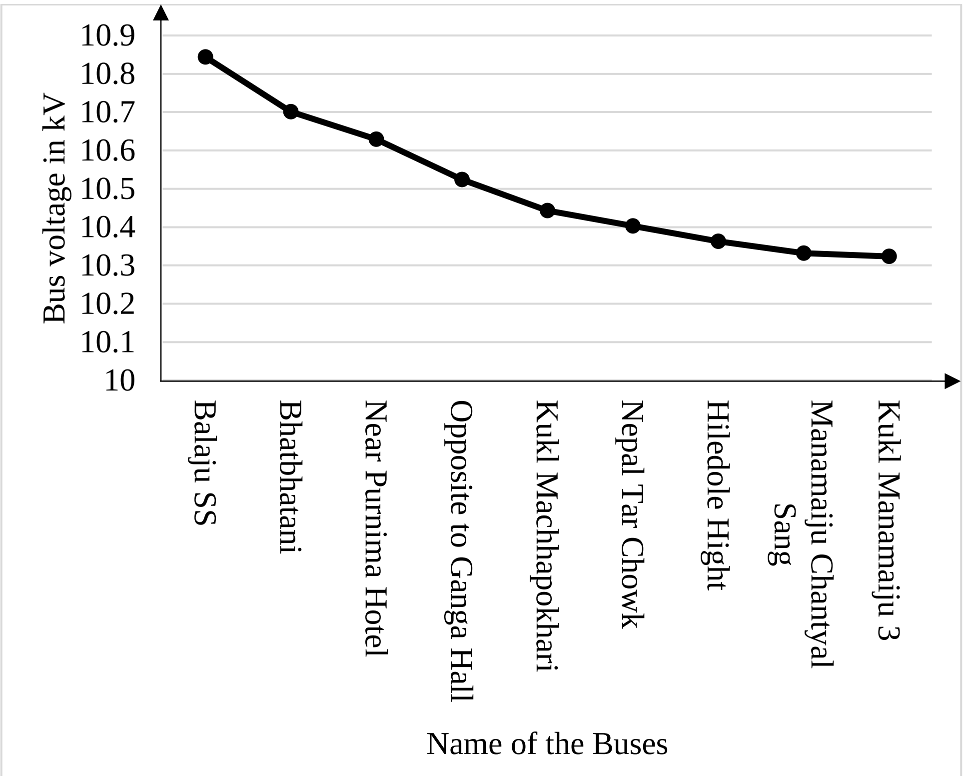


Figure 4.11 Voltage Profile of Bishnumati Feeder before solar PV injection

From Figure 4.11, with increase in distance from the substation the voltage drop will go increasing, the starting voltage at Bishnumati feeder is about 10.88 kV, and voltage start decreasing up to around 10.3 kV at far end of the substation. From IEEE standard, the distribution voltage level can vary about ±5% i.e., for 11kV system voltage can drop up to 10.45 kV. But here voltage is drop greater than 5% so voltage profile improvement by installing solar PV is essential. Along with voltage profile, the major parameter obtain from load flow analysis before solar photo-voltaic injection is shown in Table 4.1 .

Table 4.1 Overall output of Load flow analysis before solar PV injection

S.N.	Parameter	Value
1.	Study Area	Bishnumati Feeder
2.	No. of Buses	57
3.	Branches	56
4.	Generator	0
5.	Power Grids	1
6.	Load-MW	5.426
7.	Load-MVAR	2.628
8.	Generation-MW (active power supply by power grid)	5.596
9.	Generation-MVAR (reactive power supply by grid)	2.988
10.	Loss-MW	0.17
11.	Loss-MVAR	0.36

Table 4.1. show the major outcome of load flow analysis, from one power grid (i.e., from Balaju Substation) load of 5.426MW is supplied with loss of 0.17 MW. Total of 2.988 MVAR generation, about 0.36 MVAR reactive power is loss. From load flow analysis all bus voltage before injection of solar photo-voltaic into the grid shown in Table C.1 at APPENDIX C, which show voltage is gradually decreases from substation to the far from substation. The voltage is about 10.8438 kV at substation and 10.46 kV

at machhapokhari chowk and about 10.3235 kV at KUKL Manamaeju. From these data voltage is decreases at mid and far end of substation and voltage enhancement is inevitable, which is done here by injecting the solar photo-voltaic into the grid.

4.5.2 After solar PV injection into grid

After solar PV injection at different location of Bishnumati feeder, the voltage profile is improved which is shown in Figure 4.12. before solar PV injection into the grid minimum voltage is at KUKL Manamaeju 3, which is about 10.32 kV, and it is lower than the IEEE standard. IEEE suggest that for distribution of electrical energy bus voltage should not be change ±5%. This criteria in not met by Bishnumati feeder before injection of solar PV. When solar PV is injected into the grid losses and power demand from grid is reduced, due to power is locally supplied by solar PV. The major improvement after solar PV injection into the grid is voltage profile. The minimum voltage is at KUKL Manamaeju 3, about 10.53 kV. After installation of solar PV voltage regulation is maintain within the ±5 % range as set by IEEE standard.

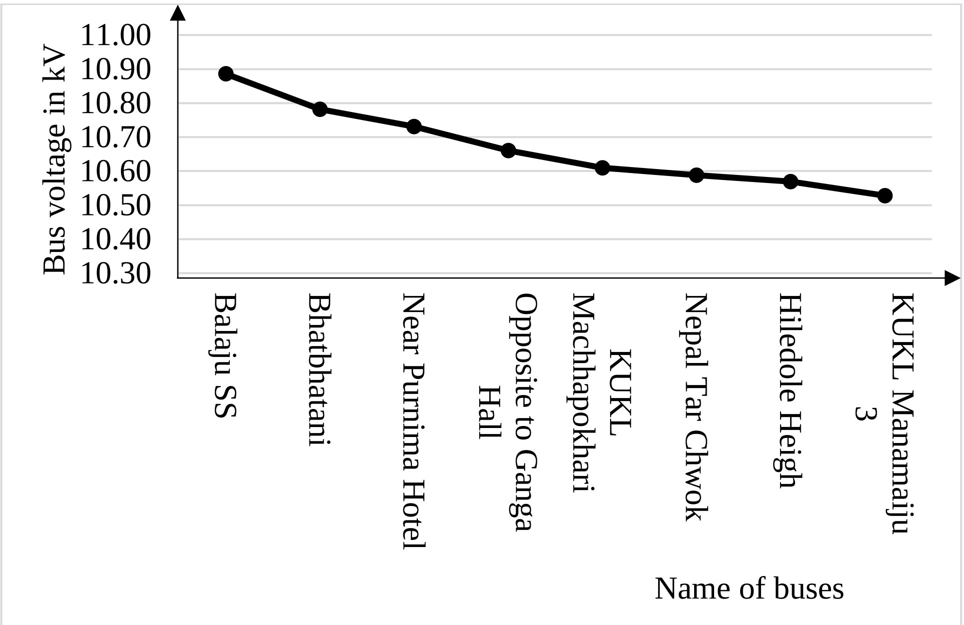


Figure 4.12 Voltage profile of feeder after solar PV injection into grid

The voltage of all buses and major parameter of load flow analysis after injection solar PV in the grid is Table C.2 at APPENDIX C.

4.5.3 Voltage profile comparison

Before installation of solar PV into the grid, the minimum voltage is 10.32 kV at KUKL Manamaeju, which is 93.85% of nominal voltage of 11 kV. This result doesn't meet the IEEE standard. According to IEEE standard for distribution of electrical energy voltage at any buses should not below 95% of nominal value. The bus voltage after PV injection is improve to 10.53 kV at KUKL Manamaeju, which is 95.727% of nominal voltage and hence maintain the IEEE standard. Voltage profile comparison before and after solar PV injection into grid is shown in Figure 4.13.

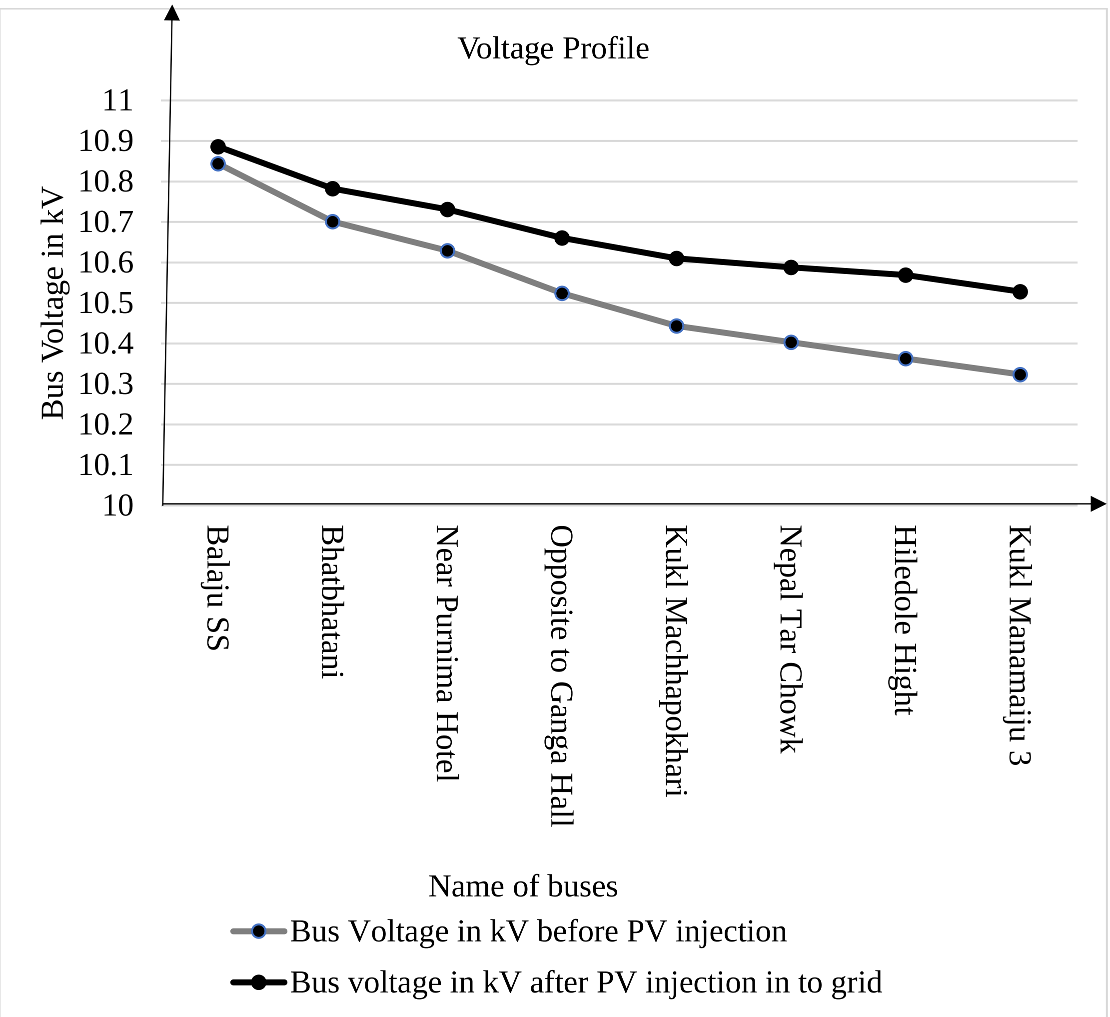


Figure 4.13 Voltage profile comparison

Figure 4.13. shows voltage profile comparison of before and after solar PV injected into the grid. In this analysis solar PV is injected into the grid from eleven different part. From eleven building total of 1 MW power is injected into the grid. Same analysis is performed total of 1 MW power injected from the one point where voltage is lowest before solar PV injected into the grid. Figure 4.14show the voltage profile comparison before solar PV injection into the grid, after solar PV injected into the grid and after total power injected from one point, where voltage is minimum before solar PV injection into the grid.

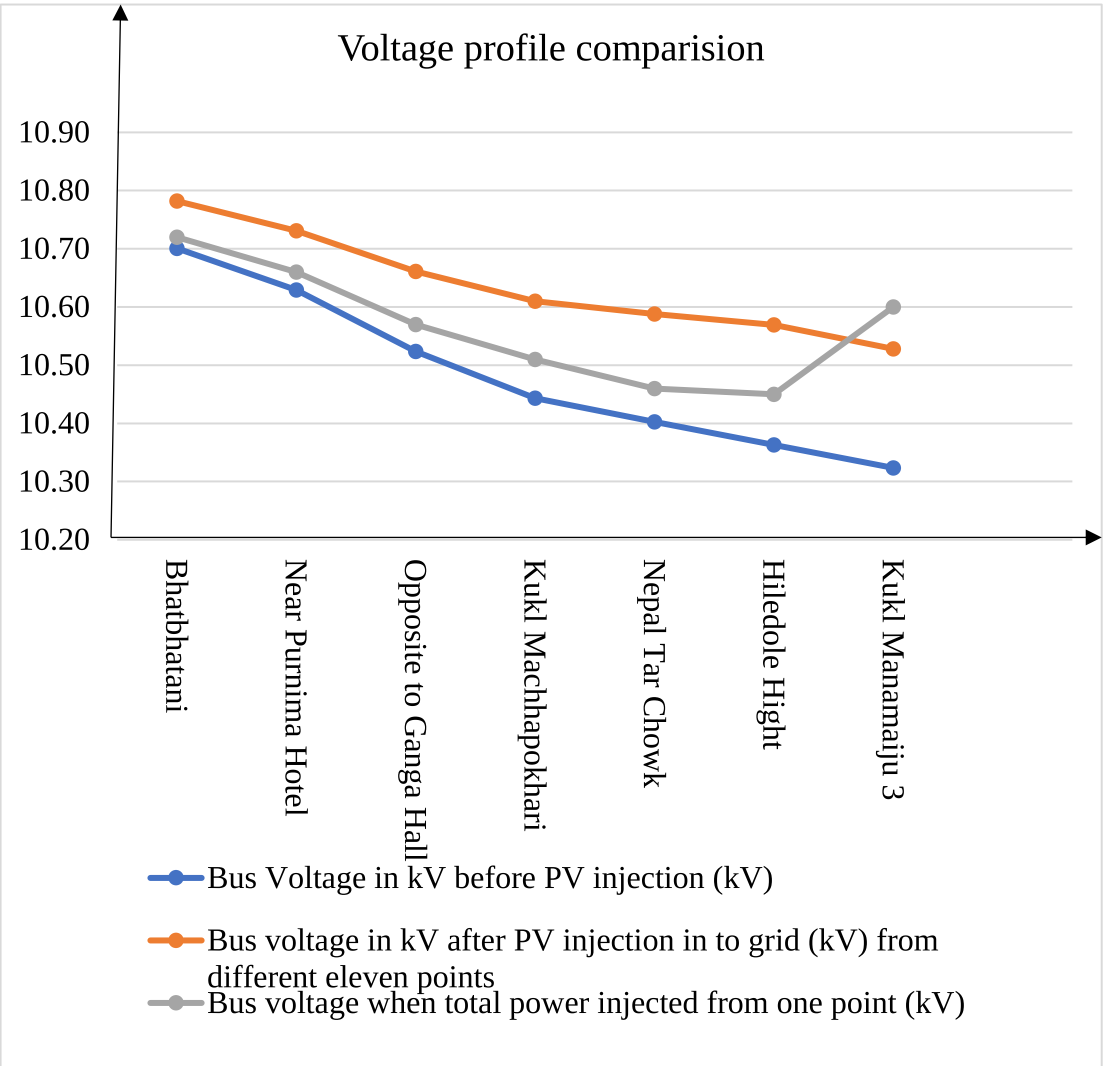


Figure 4.14 Voltage profile comparison when all solar PV injected from one point

From Figure 4.14. when all of the power is injected into the point where voltage profile is low before solar PV injection into the grid, the voltage at that point is rises and voltage profile is not improving smoothly as PV injected from different points. So solar PV injected from different location is better than injecting from single point, it also increases the reliability of the system of the system rather than injecting from single point.

For analysing the impact of voltage profile, if all of the solar PV generated from the roof top of the selected buildings is placed at midpoint of the feeder. From Figure 4.15. after injecting solar PV at the mid-point of the feeder, voltage profile is improved but its improvement is less uniform as solar PV injected from different eleven points. From this analysis it is recommended that rather than placing solar PV or DG at same point, if solar PV is injected from the different points voltage profile is uniformly improved and system reliability is improved.

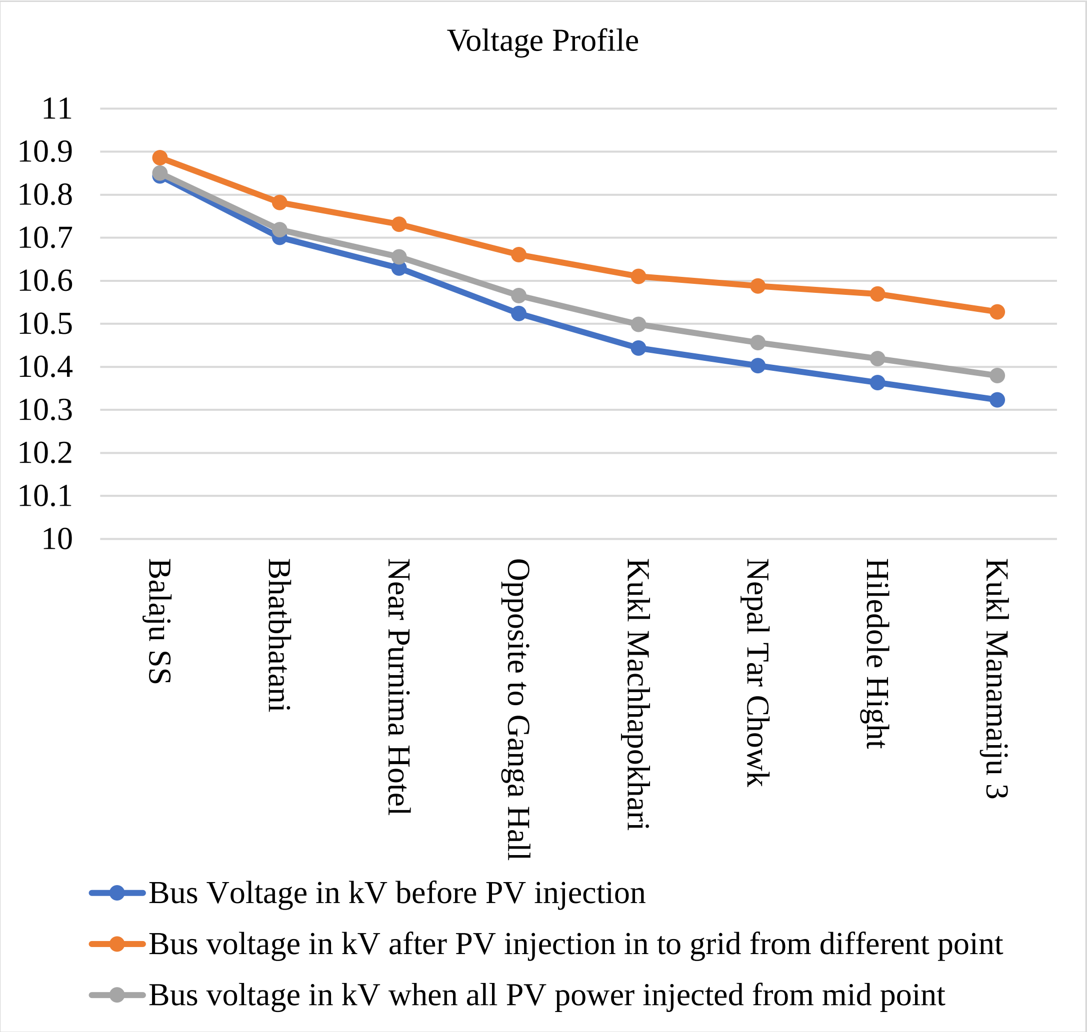


Figure 4.15 Voltage profile after injecting all solar PV from mid-point of the feeder

4.5.4 Loss Analysis

Certain power is lost during transmitting and distribution of electrical energy in the form of I^2R. due to the resistance of the conductor. The value of resistance (R) increases with increase in length of the conductor. At constant voltage the value of current is depends on the amount of power carried by the conductor i.e., higher the power to be transmitted high will be the current and causes the high losses in the system. Before solar PV injection into the grid, power demand is supplied solely by Balaju substation and high losses occurred. After injecting the solar PV into the grid, certain local power demand is fulfilled by solar PV and hence power flow from the conductor reduced. Due to low value of current, losses in the system are also low as shown in Figure 4.16.

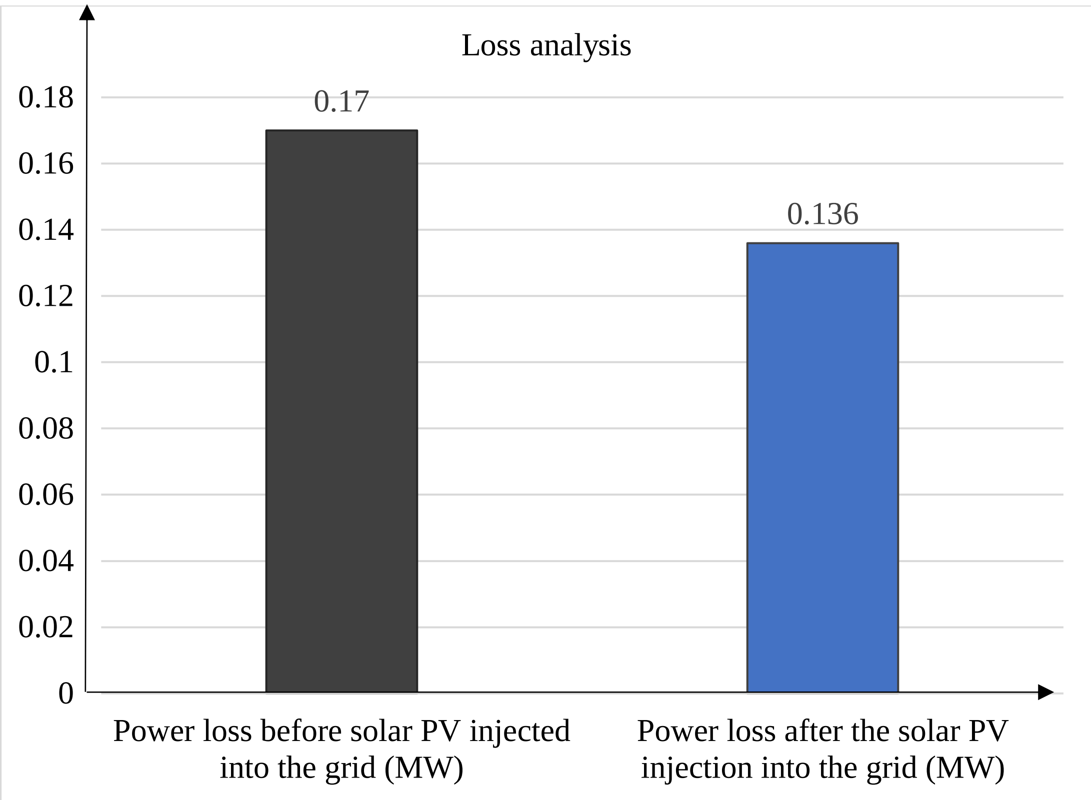


Figure 4.16 Active power loss comparison before and after solar PV injection into the grid

Before solar PV injection into the grid the power loss is 0.17 MW and after solar PV injection into the grid its value reduced to 0.136 MW, which about 20 % reduction in loss.

Before solar PV injection into the grid, the power demand of the feeder is 5.596 MW which is totally supplied by the Balaju distribution centre. Due to the large power flow high power losses (active and reactive) is occur in the feeder. During daytime solar PV able to generate the power and is injected into the grid, which reduces the high-power demand from grid. The amount of power supplied by grid before and after solar PV injection into the grid is shown in Figure 4.17.

At Bishnumati feeder penetration level of solar is maintained around 20 %. It gives the improve voltage profile and line losses reduction (active and reactive power). So solar penetration level can be increased beyond the 20 % without disturbing system dynamic and stability.

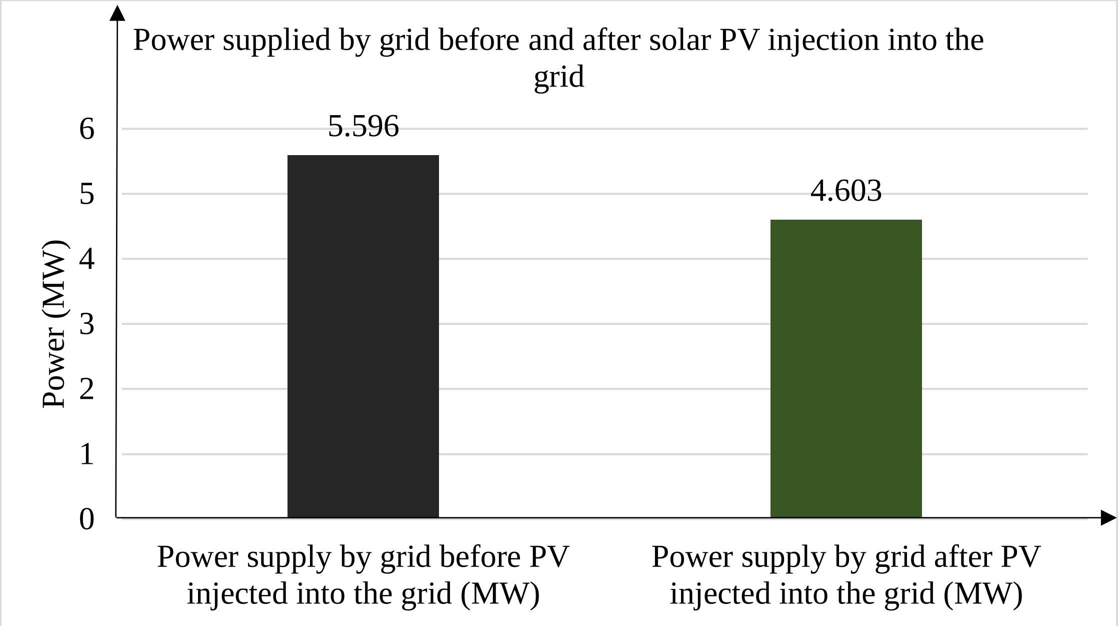


Figure 4.17 Active power supply by grid before and after solar PV injected into the grid

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions have been drawn from the study:

- From Bishnumati feeder of Balaju substation from cluster sampling total of eleven potential building is selected at starting, mid and far end of feeder. From selected building the total building foot-print area obtain is 8915.13 m^2. This area is multiplied by PVA ratio of 0.47 to find out the actual solar PV installation area and its value is 4190.11 m^2
- The install capacity solar PV from selected building is 920 kW, which is calculated through PVsyst. After finding out the installed capacity of solar PV, performance parameters are evaluated. The major performance parameter is performance ratio whose value is 0.74 with average capacity factor of 17 %.
- ETAP software is used for modelling and simulation of feeder. For load flow analysis Balaju substation is taken as slack/reference bus and all other are taken as load bus. From load flow analysis it is found that there is a high line losses and voltage at far end of substation is 10.32 kV at 11 kV nominal voltage, which is higher voltage drop at far end of substation and doesn't maintain the IEEE standard. According to IEEE standard for distribution of electrical power voltage should not be change ±5%.
- After injection of solar PV, again load flow analysis is done. From load flow result it is clearly show that power demand and line losses is reduced, and main result is voltage profile of feeder improve. It is found that minimum voltage throughout the feeder is 10.53 kV at 11 kV nominal voltage and maintain the IEEE standard.

5.2 Recommendations

Following recommendations have been drawn from the study:

- After injecting the solar PV into the grid, the voltage profile and losses are reduced so practical implementation is recommended.
- Study area can be increased by considering residential buildings and penetration on the grid.

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APPENDIX A: DATA AND OUTPUT TABLE

Table A. 1 BFA and PVA of selected buildings

S.N.	Name of Building	BFA(m^2)	PVA(m^2)
1.	Himalayan City Centre	405.11	190.40
2.	Bhatbhateni Supermarket	537.55	252.65
3.	Buddha Mall	989.83	465.22
4.	Ganga Hall	382.12	179.59
5.	Aastha Narayan Pictures Pvt. Ltd.	679.24	319.24
6.	Janamaitri Hospital	1166.60	548.30
7.	Kathmandu Upatyaka Khanepani Limited	158.48	74.49
8.	Nepal Bureau of Standard	1171.66	550.68
9.	Lotse Mall	1849.57	869.30
10.	World Link Communication	635.38	298.63
11.	Krishi Farm	939.63	441.62
Total			4190.11

Table A. 2 Major output of Himalayan City Centre

S.N.	Month	T_amb(°C)	Irradiation in kWh/m^2	E_Array (MWh)	E_grid (MWh)	PR
1.	January	8.01	164.5	3.907	3.756	0.745
2.	February	12.92	135.9	3.148	3.018	0.724
3.	March	18.68	179.2	3.905	3.742	0.681
4.	April	23.47	158.2	3.455	3.300	0.676
5.	May	25.11	162.1	3.600	3.437	0.685
6.	June	24.90	138.8	3.208	3.054	0.709
7.	July	23.52	128.5	2.997	2.845	0.712
8.	August	23.43	145.9	3.307	3.154	0.698
9.	September	22.51	139.5	3.146	3.004	0.698
10.	October	20.26	181.1	3.955	3.795	0.683
11.	November	15.12	178.1	3.968	3.814	0.701
12.	December	9.92	186.7	4.271	4.109	0.720
13.	Average	19.01	1898.5	42.866	41.028	0.702

Table A. 3 Performance parameters of selected buildings

Buildings	T_amb(^oC)	Radiation in KWh/m^2	E_Array (MWh)	E_grid (MWh)	PR
Himalayan City Centre	19.01	1898.5	42.866	41.028	0.702
Bhatbhateni Supermarket	19.03	1903.4	64.745	62.571	0.777
Buddha Mall	19.03	1898.7	123.68	119.52	0.771
Ganga Hall	19.03	1900.7	47.641	46.040	0.787
Astha Narayan Pictures pvt. Ltd.	18.88	1895.8	85.259	82.381	0.785
Janamaitri Hospital	19.03	1899.9	134.18	130.30	0.713
Kathmandu Upatyaka Khanepani limited	19.03	1856.2	16.192	15.493	0.705
Nepal Bureau of standard	19.03	1917.8	134.59	128.84	0.708
Lotse Mall	19.03	1918.3	214.80	206.26	0.710
World Link Comm.	19.02	1919.1	73.880	71.526	0.785
Krishi Farm	19.03	1898.5	80.486	78.080	0.713

APPENDIX B: PVsyst REPORT

Project: Astha Narayan Pictures pvt. ltd.

Variant: New simulation variant

PVsyst V7.2.5
VC0, Simulation date:
18/09/21 10:12
with v7.2.5

Project summary

Geographical Site	Situation		Project settings	
Astha Narayan Picture pvt. ltd	Latitude	27.74 °N	Albedo	0.20
Nepal	Longitude	85.30 °E		
	Altitude	1325 m		
	Time zone	UTC+5.5		

Meteo data
Astha Narayan Picture pvt. ltd
Meteonorm 8.0 (1981-2010), Sat=100% - Synthetic

System summary

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	30 / -2 °		

System information

PV Array		Inverters	
Nb. of modules	187 units	Nb. of units	11 units
Pnom total	52.4 kWp	Pnom total	44.0 kWac
		Pnom ratio	1.190

Results summary

Produced Energy	82.38 MWh/year	Specific production	1573 kWh/kWp/year	Perf. Ratio PR	78.53 %

Table of contents

Version 7.2.5

PVSYST
PHOTOVOLTAIC SOFTWARE

PVsyst - Simulation report

Grid-Connected System

Project: Astha Narayan Pictures pvt. ltd.

Variant: New simulation variant
No 3D scene defined, no shadings
System power: 52.4 kWp
Astha Narayan Picture pvt. ltd - Nepal

General parameters

Grid-Connected System | **No 3D scene defined, no shadings**

PV Field Orientation

Orientation		**Sheds configuration**	**Models used**	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	30 / -2 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate
Horizon		**Near Shadings**	**User's needs**	
Free Horizon		No Shadings	Unlimited load (grid)	

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	5BB Sunmodule Bisun SW 280 DUO Black	Model	UNO-DM-4.0-TL-PLUS
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	280 Wp	Unit Nom. Power	4.00 kWac
Number of PV modules	187 units	Number of inverters	11 units
Nominal (STC)	52.4 kWp	Total power	44.0 kWac
Modules	17 Strings x 11 In series	Operating voltage	90-580 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.19
Pmpp	47.1 kWp		
U mpp	311 V		
I mpp	152 A		
Total PV power		**Total inverter power**	
Nominal (STC)	52 kWp	Total power	44 kWac
Total	187 modules	Nb. of inverters	11 units
Module area	314 m²	Pnom ratio	1.19

Array losses

Array Soiling Losses		**Thermal Loss factor**		**DC wiring losses**	
Loss Fraction	3.0 %	Module temperature according to irradiance		Global array res.	34 mΩ
		Uc (const)	20.0 W/m²K	Loss Fraction	1.5 % at STC
		Uv (wind)	0.0 W/m²K/m/s		
Module Quality Loss		**Module mismatch losses**		**Strings Mismatch loss**	
Loss Fraction	-0.9 %	Loss Fraction	2.0 % at MPP	Loss Fraction	0.1 %

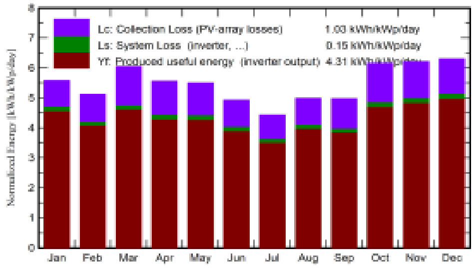
IAM loss factor
ASHRAE Param: IAM = 1 - bo(1/cosi -1)
bo Param. 0.05

Main results

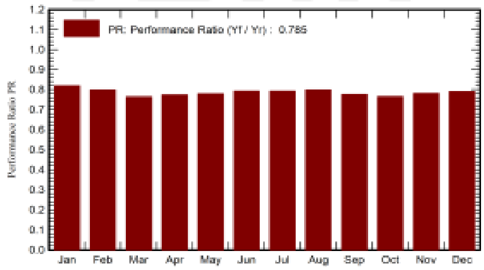
System Production

Produced Energy	82.38 MWh/year	Specific production	1573 kWh/kWp/year
		Performance Ratio PR	78.53 %

Normalized productions (per installed kWp)



Performance Ratio PR

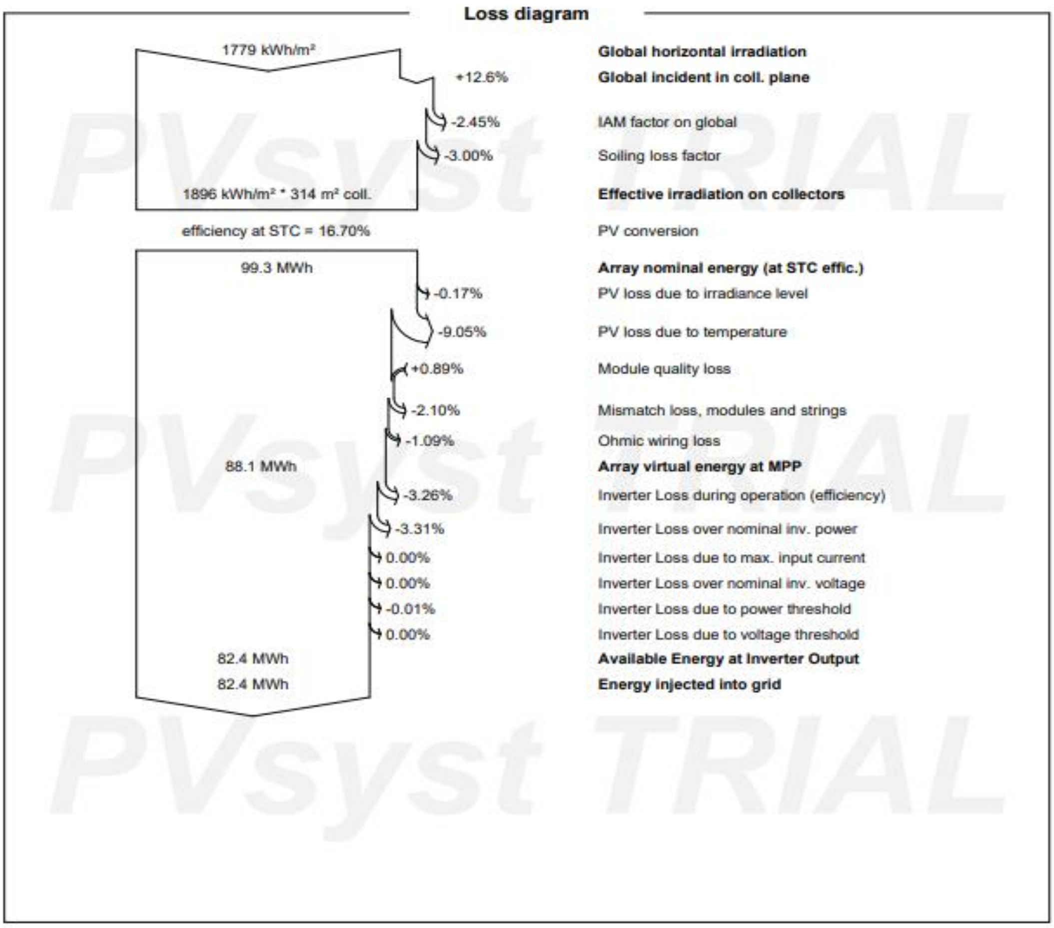


Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	ratio
January	119.3	39.23	7.92	173.2	164.5	7.673	7.422	0.818
February	112.8	45.19	12.82	143.1	135.9	6.198	5.993	0.800
March	166.1	57.00	18.59	187.8	178.2	7.767	7.505	0.763
April	166.1	74.18	23.37	166.9	157.4	6.994	6.756	0.773
May	185.8	83.83	24.90	170.6	160.6	7.207	6.960	0.779
June	166.1	86.12	24.70	147.9	138.8	6.360	6.139	0.793
July	152.4	80.11	23.41	137.5	128.8	5.922	5.711	0.793
August	160.3	90.45	23.33	154.8	145.7	6.707	6.478	0.799
September	139.8	68.02	22.41	149.4	141.2	6.281	6.068	0.776
October	153.6	47.59	20.16	190.7	181.0	7.904	7.643	0.765
November	131.3	32.99	14.92	186.3	177.6	7.882	7.618	0.781
December	125.9	24.80	9.72	195.3	186.1	8.363	8.087	0.791
Year	1779.5	729.52	18.88	2003.5	1895.8	85.259	82.381	0.785

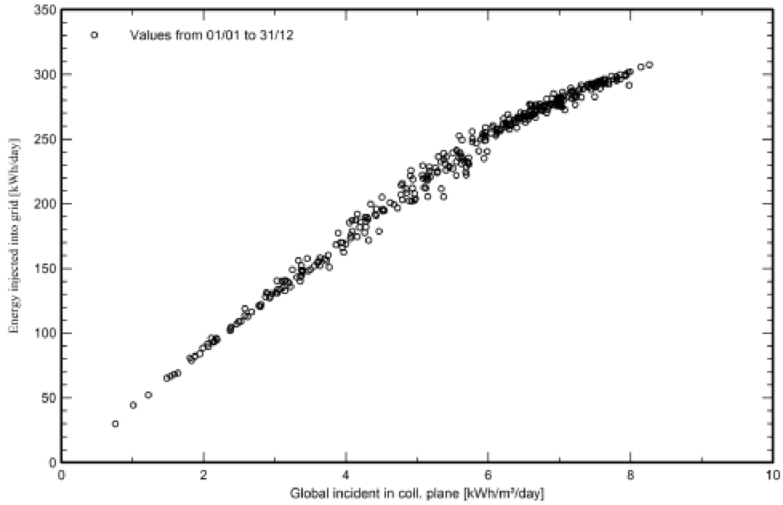
Legends

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

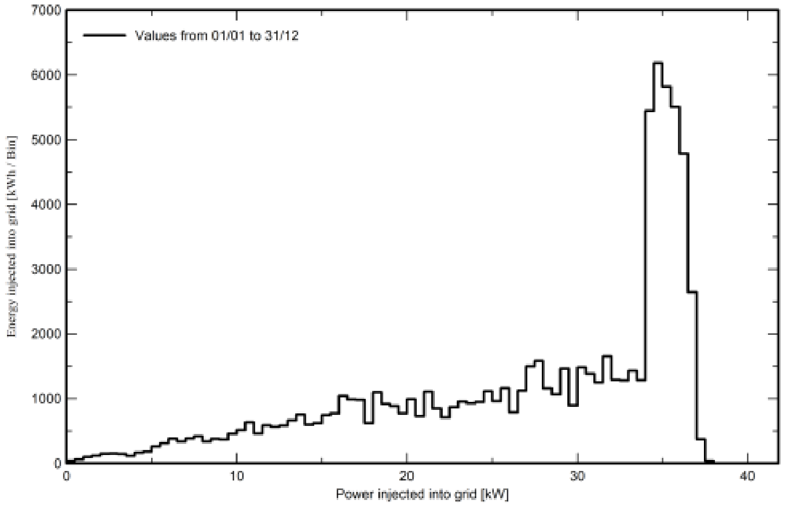

Loss diagram
1779 kWh/m²
Global horizontal irradiation
+12.6%
Global incident in coll. plane
-2.45%
IAM factor on global
-3.00%
Soiling loss factor
1896 kWh/m² * 314 m² coll.
Effective irradiation on collectors
efficiency at STC = 16.70%
PV conversion
99.3 MWh
Array nominal energy (at STC effic.)
-0.17%
PV loss due to irradiance level
-9.05%
PV loss due to temperature
+0.89%
Module quality loss
-2.10%
Mismatch loss, modules and strings
-1.09%
Ohmic wiring loss
88.1 MWh
Array virtual energy at MPP
-3.26%
Inverter Loss during operation (efficiency)
-3.31%
Inverter Loss over nominal inv. power
0.00%
Inverter Loss due to max. input current
0.00%
Inverter Loss over nominal inv. voltage
-0.01%
Inverter Loss due to power threshold
0.00%
Inverter Loss due to voltage threshold
82.4 MWh
Available Energy at Inverter Output
82.4 MWh
Energy injected into grid
PVsyst TRIAL
PVsyst TRIAL
PVsyst TRIAL

Special graphs

Daily Input/Output diagram



System Output Power Distribution



PVsyst V7.2.5
VC0, Simulation date:
18/09/21 09:54
with v7.2.5

Project: Buddha Mall
Variant: New simulation variant

Project summary

Geographical Site	Situation		Project settings	
Himalayan City Centre	Latitude	27.74 °N	Albedo	0.20
Nepal	Longitude	85.30 °E		
	Altitude	1304 m		
	Time zone	UTC+5.5		

Meteo data
Buddha Mall
Meteonorm 8.0 (1981-2010), Sat=100% - Synthetic

System summary

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	30 / -1 °		

System information

PV Array		Inverters	
Nb. of modules	276 units	Nb. of units	16 units
Pnom total	77.3 kWp	Pnom total	64.0 kWac
		Pnom ratio	1.208

Results summary

Produced Energy	119.5 MWh/year	Specific production	1547 kWh/kWp/year	Perf. Ratio PR	77.07 %

Table of contents

Version 7.2.5

PVsyst - Simulation report

Grid-Connected System

Project: Buddha Mall
Variant: New simulation variant
No 3D scene defined, no shadings
System power: 77.3 kWp
Himalayan City Centre - Nepal

General parameters

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation

Orientation		**Sheds configuration**	**Models used**	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	30 / -1 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

Horizon	**Near Shadings**	**User's needs**
Free Horizon	No Shadings	Unlimited load (grid)

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	5BB Sunmodule Bisun SW 280 DUO Black	Model	UNO-DM-4.0-TL-PLUS
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	280 Wp	Unit Nom. Power	4.00 kWac
Number of PV modules	276 units	Number of inverters	16 units
Nominal (STC)	77.3 kWp	Total power	64.0 kWac
Modules	23 Strings x 12 In series	Operating voltage	90-580 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.21
Pmpp	69.5 kWp		
U mpp	339 V		
I mpp	205 A		

Total PV power		**Total inverter power**	
Nominal (STC)	77 kWp	Total power	64 kWac
Total	276 modules	Nb. of inverters	16 units
Module area	463 m²	Pnom ratio	1.21

Array losses

Array Soiling Losses		**Thermal Loss factor**		**DC wiring losses**	
Loss Fraction	3.0 %	Module temperature according to irradiance		Global array res.	28 mΩ
		Uc (const)	20.0 W/m²K	Loss Fraction	1.5 % at STC
		Uv (wind)	0.0 W/m²K/m/s		

Module Quality Loss		**Module mismatch losses**		**Strings Mismatch loss**	
Loss Fraction	-0.9 %	Loss Fraction	2.0 % at MPP	Loss Fraction	0.1 %

IAM loss factor

ASHRAE Param: IAM = 1 - bo(1/cosi -1)

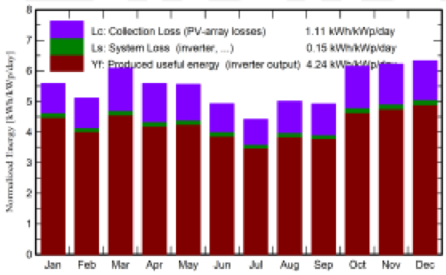
bo Param. 0.05

Main results

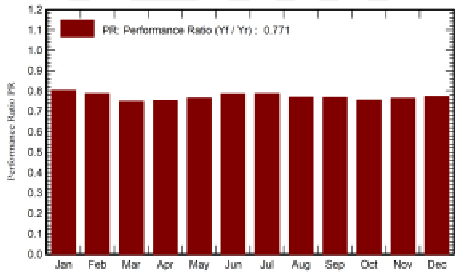
System Production

Produced Energy	119.5 MWh/year	Specific production	1547 kWh/kWp/year
		Performance Ratio PR	77.07 %

Normalized productions (per installed kWp)



Performance Ratio PR



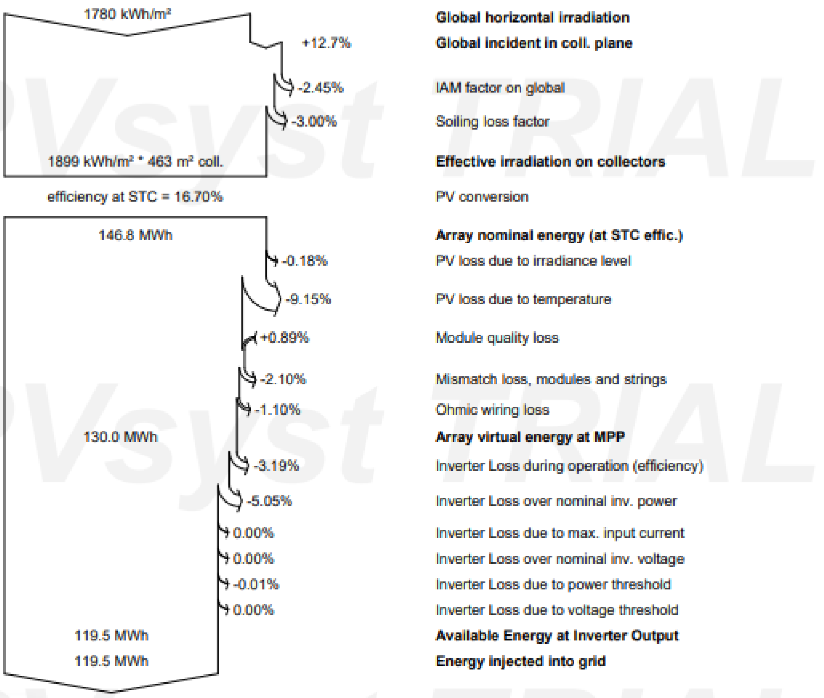
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	119.3	39.23	8.01	173.2	164.5	11.11	10.75	0.803
February	112.8	45.22	13.02	143.1	135.9	8.99	8.69	0.786
March	166.1	57.18	18.78	188.7	179.2	11.31	10.93	0.749
April	166.1	69.07	23.47	167.6	158.3	10.08	9.73	0.751
May	185.9	83.13	25.11	172.3	162.2	10.55	10.19	0.765
June	166.3	90.57	24.90	148.0	138.8	9.30	8.98	0.785
July	152.4	79.17	23.52	137.2	128.5	8.64	8.34	0.786
August	160.3	77.90	23.43	155.1	145.9	9.55	9.23	0.770
September	140.1	68.64	22.51	147.8	139.6	9.10	8.79	0.769
October	153.6	49.07	20.26	190.8	181.1	11.49	11.11	0.754
November	131.3	32.42	15.12	186.8	178.1	11.43	11.04	0.765
December	125.8	23.04	9.92	196.0	186.7	12.14	11.74	0.775
Year	1780.1	714.65	19.03	2006.7	1898.7	123.68	119.52	0.771

Legends

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

Loss diagram



APPENDIX C: ETAP SIMULATION AND OUTPUT

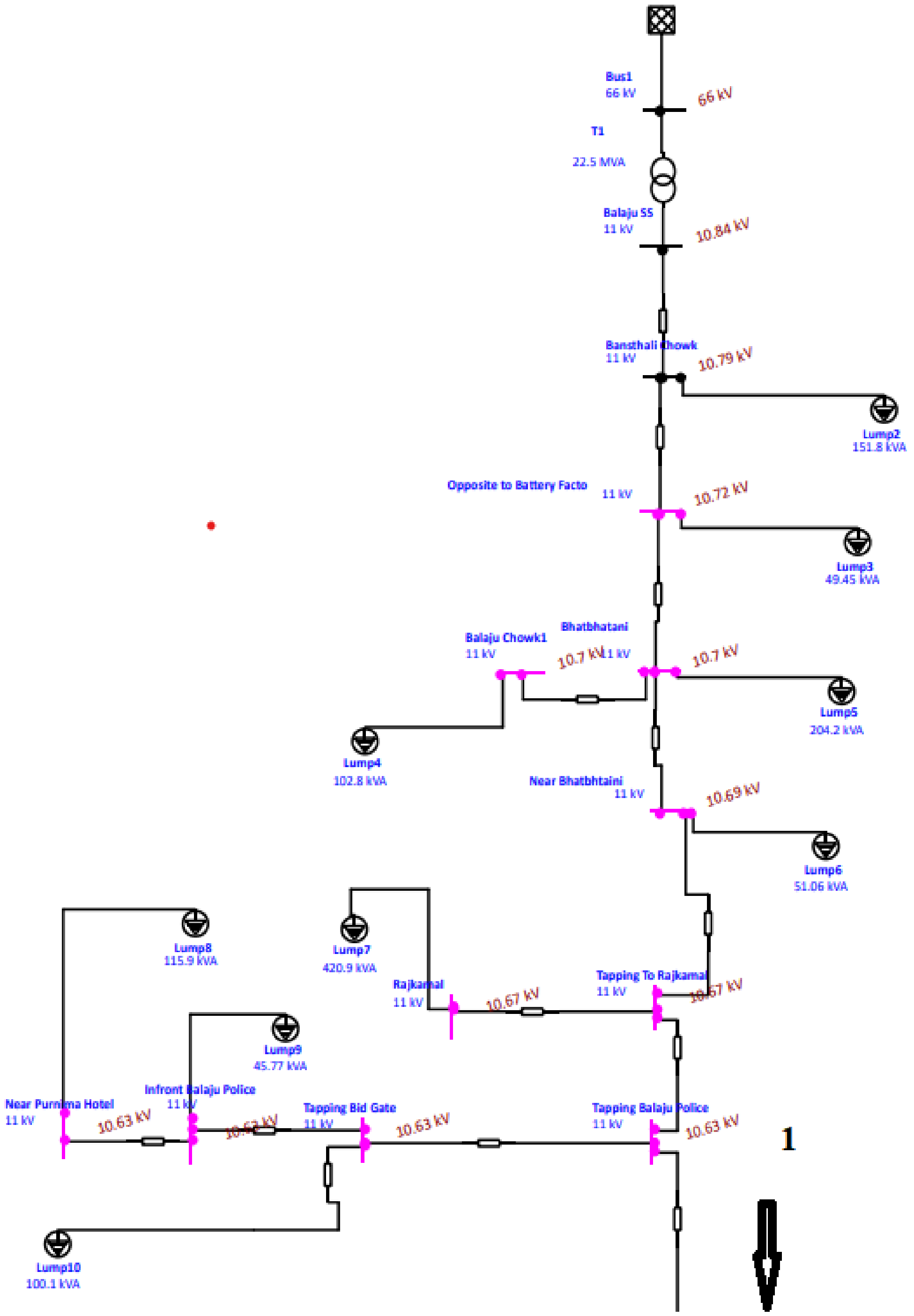


Figure C. 1 ETAP modelling of Bishnumati feeder before injection of solar PV (1)

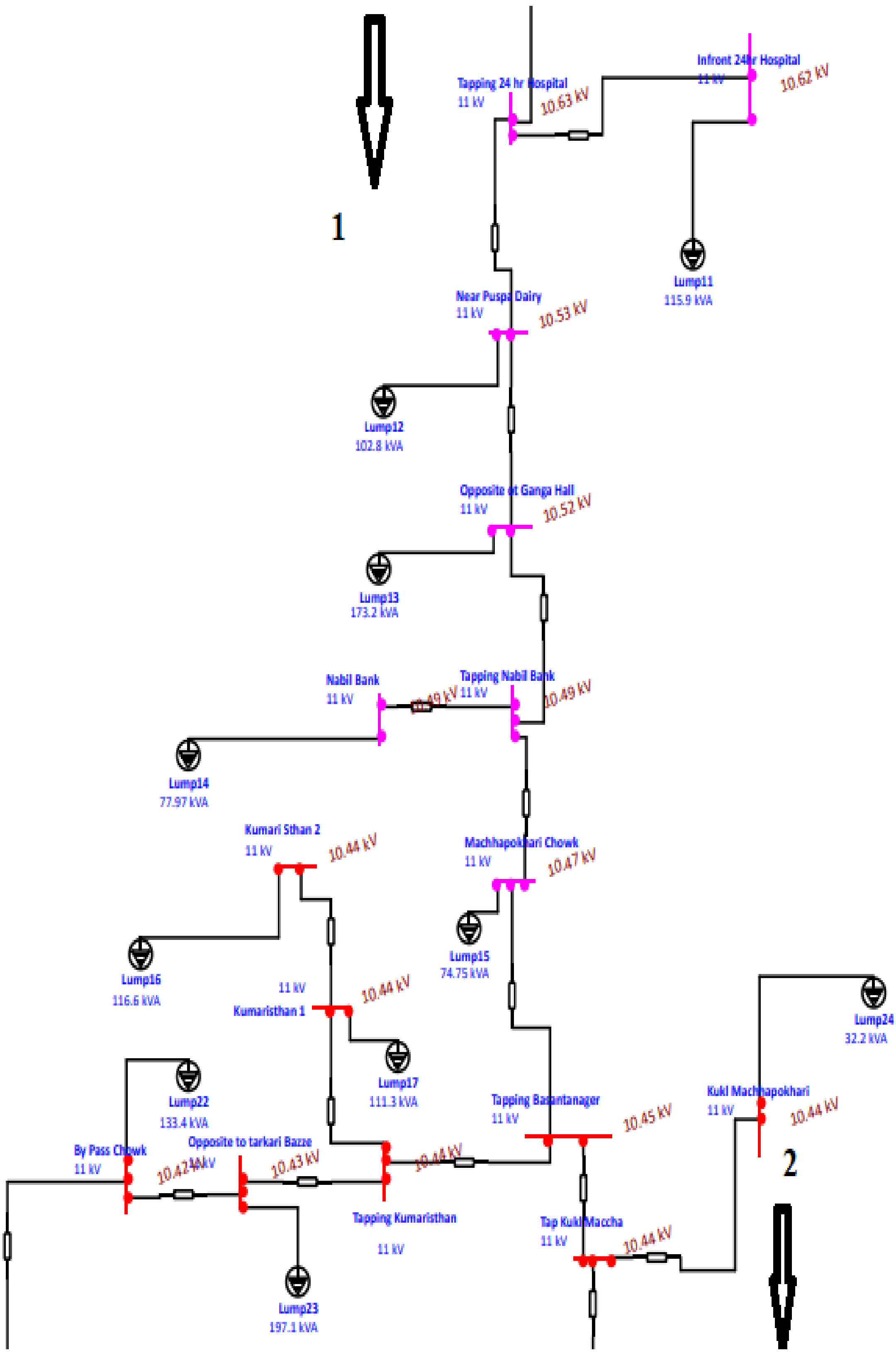


Figure C. 2 ETAP modelling of Bishnumati feeder before injection of solar PV (2)

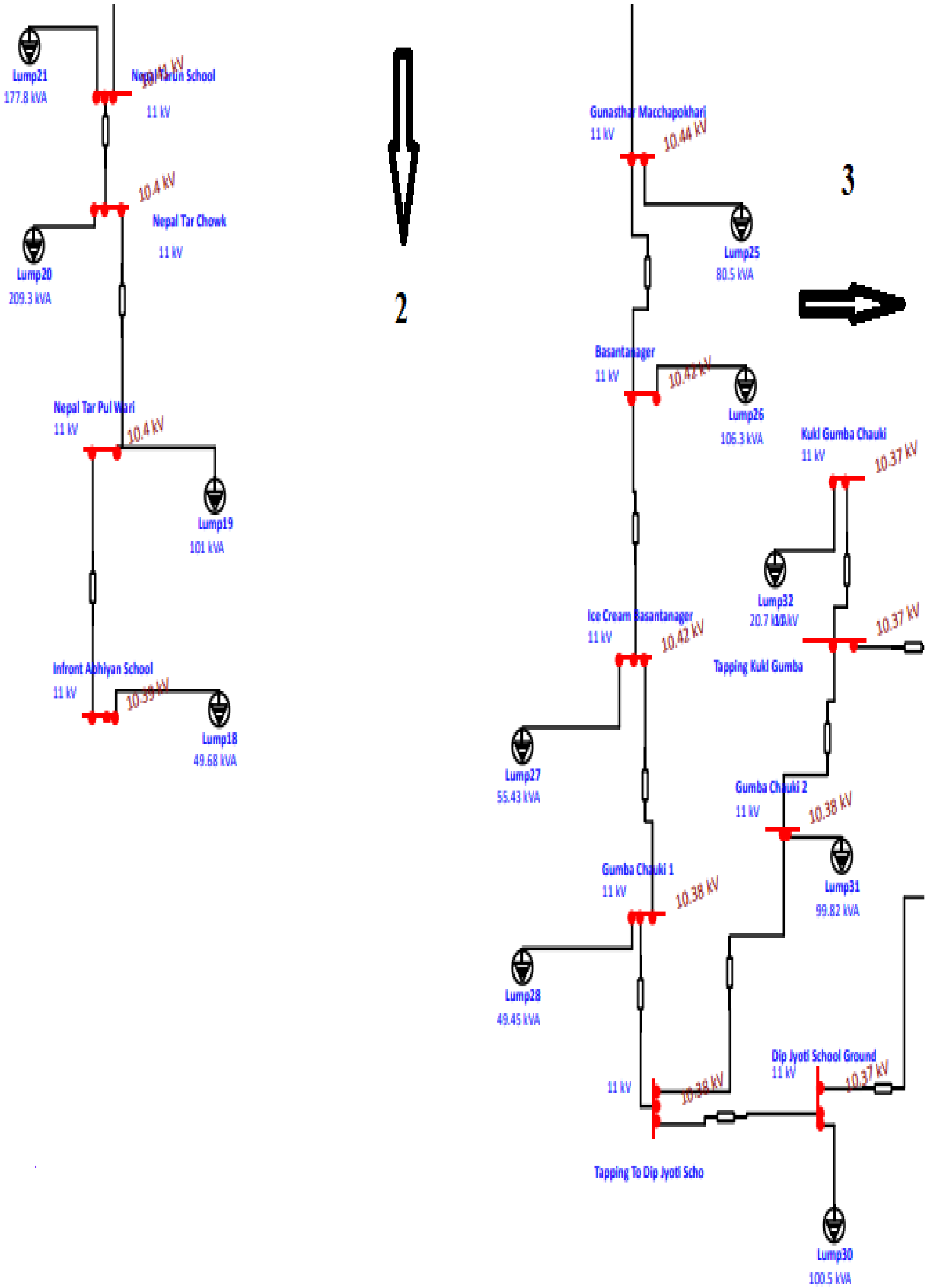


Figure C. 3 ETAP modelling of Bishnumati feeder before injection of solar PV (3)

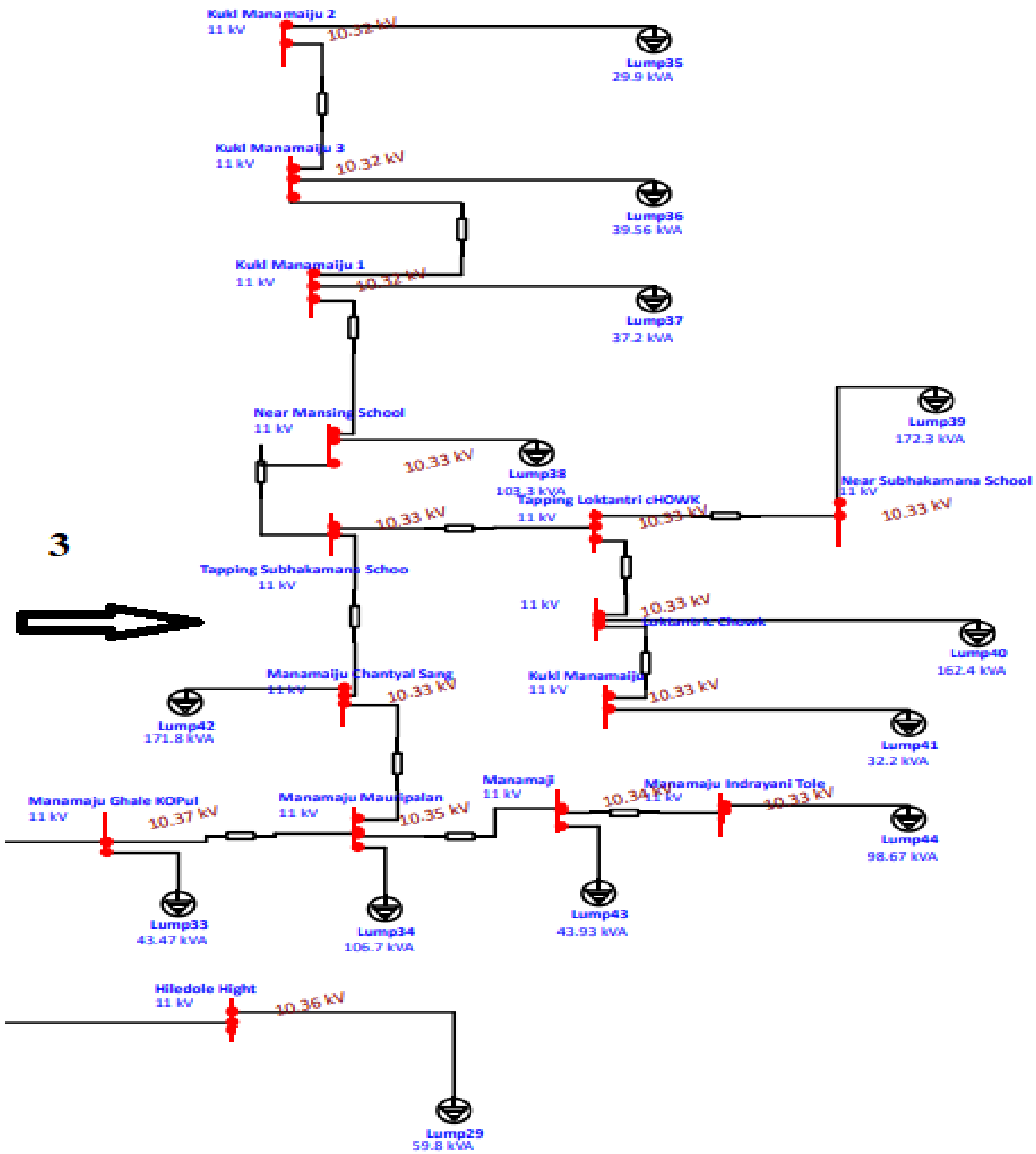


Figure C. 4 ETAP modelling of Bishnumati feeder before injection of solar PV (4)

Table C. 1 Bus voltage before injection of solar PV

Bus ID	Nominal kV	Voltage
Balaju SS	11	98.58
Bansthali Chowk	11	98.13
Opposite to Battery Facto	11	97.49
Balaju Chowk1	11	97.28
Bhatbhateni	11	97.28
Near Bhatbhateni	11	97.2
Tapping To Rajkamal	11	97.04
Rajkamal	11	97.03
Tapping Balaju Police	11	96.67
Infront Bid Gate	11	96.66
Tapping Bid Gate	11	96.66
Infront Balaju Police	11	96.63
Near Purnima Hotel	11	96.63
Infront 24hr Hospital	11	96.59
Tapping 24 hr Hospital	11	96.59
Near Puspa Dairy	11	95.72
Opposite to Ganga Hall	11	95.67
Nabil Bank	11	95.38
Tapping Nabil Bank	11	95.38
Machhapokhari Chowk	11	95.16
Tapping Basantanager	11	94.98
Kukl Machhapokhari	11	94.94
Tap Kukl Maccha	11	94.94
Tapping Kumaristhan	11	94.91
Gunasthar Macchapokhari	11	94.89
Kumaristhan 1	11	94.89
Kumaristhan 2	11	94.88
Opposite to tarkari Bazaar	11	94.81
Bypass Chowk	11	94.76
Basantanager	11	94.73

Bus ID	Nominal kV	Voltage
Ice Cream Basantanager	11	94.71
Nepal Tarun School	11	94.67
Nepal Tar Chowk	11	94.57
Nepal Tar Pul Wari	11	94.56
Infront Abhiyan School	11	94.5
Gumba Chauki 1	11	94.35
Tapping To Dip Jyoti School	11	94.34
Gumba Chauki 2	11	94.33
Kukl Gumba Chauki	11	94.3
Tapping Kukl Gumba	11	94.3
Manamaeju Ghale Ko Pul	11	94.29
Dip Jyoti School Ground	11	94.23
Hiledole Hight	11	94.21
Manamaeju Mauripalan	11	94.11
Manamaiju	11	93.96
Manamaiju Chantyal Sang	11	93.93
Tapping Subhakamana School	11	93.91
Manamaeju Indrayani Tole	11	93.88
Tapping Loktantri Chwok	11	93.88
Kukl Manamaiju	11	93.87
Loktantric Chowk	11	93.87
Near Mansing School	11	93.87
Near Subhakamana School	11	93.87
Kukl Manamaiju 1	11	93.86
Kukl Manamaiju 2	11	93.85
Kukl Manamaiju 3	11	93.85

Table C. 2 Bus voltage and loading after injection of solar PV into grid

Bus ID	Nominal kV	Voltage	kW Loading
Balaju SS	11	10.886	4150.8
Bansthali Chowk	11	10.85	4144.8
Opposite to Battery Facto	11	10.798	3992
Bhatbhateni	11	10.782	3942.4
Balaju Chowk1	11	10.781	92.53
Near Bhatbhateni	11	10.775	3664.3
Tapping To Rajkamal	11	10.763	3614.8
Rajkamal	11	10.762	378.8
Tapping Balaju Police	11	10.735	3229
Infront Bid Gate	11	10.734	90.04
Tapping Bid Gate	11	10.734	235.6
Infront Balaju Police	11	10.731	145.5
Near Purnima Hotel	11	10.731	104.3
Infront 24hr Hospital	11	10.729	104.3
Tapping 24 hr Hospital	11	10.729	2991.9
Near Puspa Dairy	11	10.665	2873.1
Opposite to Ganga Hall	11	10.661	2779.7
Nabil Bank	11	10.641	70.17
Tapping Nabil Bank	11	10.641	2619.5
Machhapokhari Chowk	11	10.626	2546.3
Tapping Basantanager	11	10.613	2476.6
Tap Kukl Maccha	11	10.611	1488.3
Kukl Machhapokhari	11	10.61	28.98
Tapping Kumaristhan	11	10.608	987.5
Gunasthar Macchapokhari	11	10.607	1459
Kumaristhan 1	11	10.606	205.1
Kumaristhan 2	11	10.605	104.9
Opposite to tarkari Bazaar	11	10.601	781.9
Bypass Chowk	11	10.598	604.3
Basantanager	11	10.597	1385.3

Bus ID	Nominal kV	Voltage	kW Loading
Ice Cream Basantanager	11	10.595	1289.5
Nepal Tarun School	11	10.593	484.1
Nepal Tar Chowk	11	10.588	324
Nepal Tar Pul Wari	11	10.588	135.6
Infront Abhiyan School	11	10.587	44.71
Gumba Chauki 1	11	10.573	1237.5
Gumba Chauki 2	11	10.572	1048.5
Tapping To Dip Jyoti School	11	10.572	1192.9
Dip Jyoti School Ground	11	10.569	144.3
Hiledole Hight	11	10.569	53.82
Kukl Gumba Chauki	11	10.569	18.63
Tapping Kukl Gumba	11	10.569	958.5
Manamaeju Ghale ko Pul	11	10.568	939.8
Manamaeju Mauripalan	11	10.555	899.8
Manamaiju	11	10.552	128.4
Manamaeju Indrayani Tole	11	10.55	88.8
Manamaiju Chantyal Sang	11	10.537	674.1
Tapping Subhakamana School	11	10.534	519.3
Tapping Loktantri Chwok	11	10.531	330.2
Kukl Manamaiju	11	10.53	28.98
Loktantric Chowk	11	10.53	175.1
Near Mansing School	11	10.53	189
Near Subhakamana School	11	10.53	155
Kukl Manamaiju 1	11	10.529	96
Kukl Manamaiju 2	11	10.528	26.91
Kukl Manamaiju 3	11	10.528	62.52