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Performance Assessment of 8.5 MW Grid Connected Solar PV Plant in Butwal, Nepal

by

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A THESIS

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Performance Assessment of 8.5 MW Grid Connected Solar PV Plant in Butwal, Nepal"** submitted by Kishor Ghimire, in partial fulfillment of the requirements for the degree of Master in Energy System Planning and Management.

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Abstract

The rising energy demand in Nepal has prompted the matter of energy security. Further, to maintain the energy mix it is essential to use alternative renewable resources. Grid connected megawatt scale PV systems possibly are the best alternatives. The Butwal solar project is the leading large Solar PV project built and operated by an independent power producer in Nepal. The growth of investment in such a large grid connected solar project will ultimately depend on its performance. Hence the designed system and performance parameters are needed to be properly analyzed and studied so that it provides some guidelines for upcoming future installations.

The performance analysis of an 8.5 MW grid connected PV power plant installed at Butwal, Nepal is worked out. By analyzing the plant's first-year operational performance, it is found that final yield, reference yield, Capacity Utilization Ratio (CUF) and Performance Ratio (PR) vary from 2.33 to 3.80 kWh/kWp-day, 3.87 to 6.20 kWh/kWp-day, 9.7 to 15.8% and 54 to 77% respectively. The annual average final yield, CUF and PR are found to be 1140.4 kWh/kWp, 13%, 64.2% in close agreement with PVSYST estimated outcomes of 1372 kWh/kWp, 15% and 72% respectively. The performance of the plant is compared with PV systems installed in various parts of the world and found comparable. Financial analysis shows that plant discounted payback period is 16.3 years with the proper return of NRs. 58.88 million in its useful life. The LCOE is found to be 6.7 NRs/kWh. Carbon emission balance analysis shows that 952 tCO_2 emissions are replaced in a plant's useful life. The power flow from this plant impacts the injected 33 kV substation causing a substantial drop in power factor and a slight voltage dip in that 33 kV substation.

The findings give insight into the solar power plant's long-term performance in Nepal's Terai area under real working circumstances. The need for regular maintenance against array capture loss, making the grid more reliable and the use of MPP having a large voltage range in the inverter is highlighted to maximize energy generation and export to the grid. Additional, supplement research studies are also recommended.

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List of Acronyms and Abbreviations

a-si	amorphous silicon
AC	Alternating Current
AEPC	Alternative Energy Promotion Centre
CO_2	Carbon dioxide
COVID – 19	Coronavirus Disease of 2019
CUF	Capacity Utilization Factor
DC	Direct Current
DoED	Department of Electricity Development
DSCR	Debt Service Coverage Ratio
ESAP	Energy Sector Assistance Programme
FIT	Feed In Tariff
GHI	Global Horizontal Irradiation
GTI	Global Tilted Irradiation
ICIMOD	International Centre for Integrated Mountain Development
IEA	International Energy Agency
IEC	International Electrotechnical Commission
INPS	Integrated Nepal Power System
IPP	Independent Power Producers
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
LCOE	Levelized Cost of Electricity
mc-si	monocrystalline silicon
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker

NEA	Nepal Electricity Authority
NLTC	No Load Tap Changer
NOCT	Normal Operating Cell Temperature
NPV	Net Present Value
ONAN	Oil Natural Air Natural
pc-si	polycrystalline silicon
PR	Performance Ratio
PV	Photo Voltaic
PVGC	Photo Voltaic Grid Connected
PPA	Power Purchase Agreement
RIDS	Rural Integrated Development Service
SCB	String Combiner Box
SHS	Stand-alone Solar Home System
SLD	Single Line Diagram
STC	Standard Test Condition
SUDIGGAA	Sustainable Distributed Generation for Grid Access to All
tCO_2	Tonnes of Carbon dioxide
TMEIC	Toshiba Mitsubishi-Electric Industrial Systems
VA	Volt Ampere
W	Watt
Wh	Watt hour
Wp	Watt Peak
Y_R	Reference Yield
Y_A	Array Yield
Y_F	Final Yield

CHAPTER ONE: INTRODUCTION

1.1 Background

The conventional sources of energy, fossil fuel, are depleting rapidly as well as seriously impacting the environment. This reason impulses to focus on other alternative sources of energy. One of the non-conventional sources which do not produce harmful gases for power generation is the Photovoltaic system. Former, rural electrification has familiarized the usage of the solar home system. Through extensive enhancement in PV manufacturing, the decline in initial cost, solar policies, government schemes, easy installation, pollution-free environment and public awareness contributed to extensive space for the utilization of solar PV energy (Thotakura et al., 2020).

Nepal has abundant biomass, wind and solar resources, but the country is unable to fully utilize these resources because of a shortage of revolutionary technical skills and investment. Nepal will be able to establish a reliable, varied energy system capable of producing power even if one source fails as grid-connected solar PV systems become more readily available. Supply diversification is another advantage. Relying only on hydropower is incredibly risky, especially as the consequences of climate change become more visible in the Himalayan region. Solar PV is a good supplement to hydropower, especially in the winter when the rivers are dry (Adhikary, 2020).

Nepal Government's policy, National Energy Crisis Mitigation and Power Development Decade Concept Paper and Action Plan 2072 BS, had aimed to energy mix by connecting alternative renewable electrical energy to the national grid with an upper limit of 10% of the total connected capacity. Accordance to this policy to maintain the energy mix, in June 2016 the Nepal Electricity Authority (NEA) had requested the proposal, looking for bids from concerned parties to install solar PV plants and supply electricity to the national grid. 18 projects with a total capacity of 61 MW were presented in the competition for 63 MW capacity projects. Out of them, the tender for the 8.5 MW Butwal grid connected solar project had been taken by Ridi Hydropower Development Company Limited (RHDL). Despite the COVID-19 pandemic and subsequent lockdown, the company finished the installation work in a year and commenced generating power in October 2020 (Bhusal, 2020).

As hydroelectric capacity is lowered in the winter, the solar PV project is projected to lessen power disruptions. Furthermore, its proximity to the load centre is intended to improve the power supply system's reliability and reduce system loss. The burden on hydropower plants is predicted to be reduced as a result of these projects. It gives the opportunity water to accumulate in storage plants like Kulekhani and peaking run of river (PROR), projects like Kaligandaki A, Middle Marsyangdi, and Chilime by running in the afternoon. The extra reserves can then be used to boost energy output during peak hours in the morning and evening (Adhikary, 2020).

The IEC standard 61724 defines the solar PV performance parameters concerning the energy production, irradiation and various losses on the system, that can be used to define the complete photovoltaic system performance. The main parameters of interest for this analysis are the performance ratio, final yield, reference yield and capacity utilization factor (Marion et al., 2005).

1.2 Rationale

Till now the main source of electrical energy in Nepal is Hydropower. Hydropower plants are more vulnerable to earthquake as it constitutes more than 60% of civil structures. Out of the 787 MW total installed capacity in the country, including off-grid, about 115 MW of hydropower generation facilities were badly damaged, while 60 MW were moderately damaged by the 2015 earthquake (GoN, 2015). Similarly, a massive flood had badly damaged 45 MW, upper Bhotekoshi HPP in 2014 (Bruen et al., 2017) and under construction 102 MW Middle Bhotekoshi in July 2020 (Magazine, 2020). Also due to climate change and global warming, water discharge in the river is decreasing year after year. Thus, relying on a single source of electricity generation source won’t lead to energy secured nation.

Due to the subsidy program adopted by the Alternative Energy Promotion Centre (AEPC) and Energy Sector Assistance Programme (ESAP), the trend of stand-alone Solar Home System (SHS) installation in Nepal has grown tremendously since 2000. The grid-connected solar system is still in its development. Installation of 1-kWp PVGC test project at Pulchowk Engineering Campus and 1.11 kWp Photo Voltaic Grid-Connected System (PVGC) at RIDS-Nepal office were two attempts in this sector in October 2012. Similarly, in 2013 installation of three 1.11 kWp PVGC Systems at NEA Minbhavan office and 53 kWp PVGC were Installed at ICIMOD, Khumaltar. Also 100 KW system at Kharipati, 65 KW at Nepal Telecom, 680 KW system at Sundharighat, each 1 MWp system at Singha Durbar and MK paper mill Nawalparasi, 500 kWp at Nepalgunj Medical College. The installation of 25 MW by NEA in Nuwakot and 8.5MW by Ridi Hydro in Butwal had made the breakthrough in large scale grid connected solar PV plants in Nepal. As the government has formulated policies of feed-in tariff (FIT) and net energy metering (NEM) energy sectors are willing to implement grid connected PV technology and it has gained momentum commercially.

A bold policy foray, mutually undertaken by the Nepal Electricity Authority's Engineering Company and the National Planning Commission prepare a workable plan for Sustainable Distributed Generation for Grid Access to All (SUDIGGAA). It presents a financially viable distributed generator for each of the 753 municipalities and optimal expansion of the national grid to each municipality. In 481 local bodies, a total of 481 MWp of solar PV projects with 500 kWh battery storage were spotted. (GoN and NEA, 2018).

According to DoED, till January 2022 many numbers of license has been issued for solar projects, where for construction 19 projects had a total capacity of 118 MW and for survey 26 projects had a total capacity of 624 MW. Also, applications are pending for 42 solar projects of a total capacity of 948 MW.

Few pieces of research have been done regarding PVGC systems in Nepal, a majority on Kathmandu valley area including feasibility study and performance analysis. As Butwal solar project is one of the leading large solar plants built and operated by independent power producers (IPP). The growth of investment on such a large PVGC project will ultimately depend on its performance. Hence the designed system and performance parameters need to be properly analyzed and studied so that it provides some guidelines for upcoming future installations.

This thesis mainly aims at the performance analysis of solar PV systems. So, the major scope of this thesis is an analysis of the existing solar system at Butwal, by simulating it on a computer program, to calculate performance. Financial analysis is done to find the basic outcomes of the project like NPV, IRR and sensitivity analysis is performed for finding the most sensitive parameter affecting financial performance. The recommendations from this thesis outcomes might be implemented in the currently existing system or can be applicable for setting up future similar projects, to be installed at various places. This research also intends to encourage IPP to develop more grid connected solar PV power plants to maintain the energy mix target.

1.3 Objective

The main objective is:

- To conduct performance analysis of 8.5 MW grid connected solar photovoltaic system installed at Butwal, Tilottama

The specific objectives are:

- To study details of an existing system and carry simulation using PVSYST
- To compare the actual performance data with simulated results of PVSYST
- To perform economic sensitive analysis for finding the most sensitive parameter affecting the financial outcome

1.4 Limitations

- The metrological data is taken from solargis website for simulation.
- The plant’s generation data is available on a monthly basis for a year.

CHAPTER TWO: LITERATURE REVIEW

2.1 Status of PV and previous research on similar field

Because fossil fuels are becoming increasingly scarce, renewable energy has grown in popularity over the previous few decades. This has also increased the importance and demand for electrical energy. In this context, the photovoltaic (PV) industry has continued to expand at a rapid pace. Solar PV electricity is an important consideration as a renewable energy source since it has a broad range of end-use applications, ranging from utilities to residential rooftops, and is dispersed globally. By 2050, it is predicted to contribute 11% of all worldwide electricity generated (IEA, 2014).

Photovoltaic capacity climbed by 95 GW in 2017, with new installations increasing by 34% year over year. By the end of 2018, global cumulative installed PV capacity had reached around 512 gigawatts (GW), with utility-scale plants accounting for about 180 GW (35%) of that total (IEA, 2017). By the end of 2018, global cumulative installed PV capacity reached about 512 gigawatts (GW), of which about 180 GW (35%) were utility-scale plants (wiki-solar,2019). In 2019, solar energy met roughly 3% of worldwide electricity consumption (IEA, 2020).

According to the International Renewable Energy Agency (IRENA) in 2019, “a sustained, dramatic decline in utility-scale solar PV electricity cost driven by lower solar PV module and system costs continued in 2018, with global weighted average Levelized cost of energy of solar PV falling to the US $0.085 per kWh, or 13% lower than projects commissioned the previous year, resulting in a decline from 2010 to 2018 of 77%”.

In the decades leading up to 2017, the average price of solar cells per watt declined dramatically. While crystalline silicon cell prices were around $77 per watt in 1977, average spot prices in August 2018 were as low as $0.13 per watt, nearly 600 times lower than in 1977 (Energy trend, 2020).

Nepal benefits from enormously fortunate climatic conditions for the use of PV power generation. A south-oriented 30° fix tilted photovoltaic installation can produce 1700 kWh/kWp/Year while it can produce 2300 kWh/kWp/Year with the inclusion of a two-axes sun tracker (Chianese et al., 2015).

In Kathmandu, Basant et al. conducted a study to understand the consequences of dust on solar panel efficiency, finding that dust deposition reduced electricity output by 3.16 percent in one day, 10.41 percent in ten days and 15.74 percent in a month. Cleaner equipment including brushes, sliders, and DC motors was also recommended.

Shrestha et al. conducted a techno-economic analysis of a one MWp Solar PV system at Trishuli in 2014, which found that the plant's energy output is 1768 MWh/year with a final yield of 4.81 kWh/kWp-day, a capacity utilization factor of 20.18 percent, and 77.3 percent of performance ratio resulting in an IRR of 12 percent over a 25-year plant life. It concludes that a utility-scale PVGC plant in Nepal is both economically and technically viable for tackling the nation's energy crises.

Similarly, a case study on PVGC one MWp solar PV for National Dasarath Stadium (Shakya et al., 2014) found that LCOE of 12.5 per kWh for 20 years, concluding that the PVGC plant can eliminate the need for diesel generator sets. In addition, a techno-economic analysis of a 64.6 kWp PVGC system installed at Sundhara, Kathmandu-Nepal Telecom office reveals that the system have a performance ratio of 0.859, capacity factor of 14.09 percent with a final yield of 3.38 kWh/kWp-day (Bajracharya et. al., 2019). The system was determined to have an LCOE of NRs.17.97/kWh saving NRs.134,000 monthly revealing discounted payback of 5.2 years with an IRR of 17.22 percent at a discount rate of percent.

Table 2.2 shows a few other studies which have been reviewed at a various stages during research work.

In the literature review, researchers have revealed the applicability of simulating software tools in modelling a PV plant along with evaluating the performance feasibility. From the review, it is found that the PVSYST software tool is widely used in analyzing solar PV systems.

Table 2.1 Review of PV system performance evaluation studies

S.N.	PVGC	PV	Performance outcomes	Reference
1	1 MWp, pradesh, India	pc-si	Final yield (Y_F) 1684 kwh/kwp/year, Capacity Utilization Factor (CUF) 20.8%, Performance Ratio (PR) 88%	Thotakura et al. 2020
2	10 MW, Ramagundam India	pc-si	The site receives a good average solar radiation of 4.97 kWh/m^2/day and an annual average temperature of about 27.3°C. Y_F of plant ranged from 1.96 to 5.07 h/d, and annual PR of 86.12%. It has 17.68% CUF with an annual energy generation of 15 798.192 MWh/annum.	Kumar and Sudhakar 2015
3	10.6 kWp, Serpong, Indonesia	pc-si	The average value of PR and CUF during the eight-month monitored period was 82.42% and 14.07% with average values of the array (Y_A), final (Y_F) and reference (Y_R) yields were 3.49 kWh/kWp/d, 3.38 kWh/kWp/d, and 4.12 kWh/kWp/d, respectively. Meanwhile, the average daily energy output of the PV system during the eight-month monitored period was 36.92 kWh per day.	Nurdiana et al 2020
4	190 kWp, Khatkar-Kalan, India	pc-si	The Y_F, Y_R and PR are found to vary from 1.45 to 2.84 kWh/kWp-day, 2.29 to 3.53 kWh/kWp-day and 55 to 83 % respectively. Average annual System efficiency 8.3 %. CUF of 9.27 % and the total estimated system losses due to irradiance, temperature, module quality, array mismatch, ohmic wiring and inverter, are found to be 31.7 %.	Sharma Chandel, 2013
5	1.72kWp, Ireland	mc-si	The Y_F, Y_R and Y_A were 2.41 kW h/kWp/day, 2.85 kW h/kWp/day and 2.62 kW h/kWp/day respectively. while the annual average daily performance ratio and capacity factors were 81.5 % and 10.1 % respectively. The annual average daily system losses, capture losses were 0.23 h/day and 0.22 h/day respectively.	Ayompe et al. 2010

S.N	PVGC	PV	Performance Outcomes	Reference
6	2×2.04 kWp, Morocco	mc-si, pc-si	Y_F = 5.17h for mc-si & 5.26h for pc-si, CF = 21.56% for mc-si & 21.93% for pc-si, and PF = 80.66% for mc-si & 82% for pc-si. The monthly system efficiency varied between 10.59 % and 13.60% for mc-Si and between 10.20 % and 13.73% for pc-Si. Tracking the accumulated cash flow versus time allows the computation of the payback, which is approximately 12.63 years for mc-Si, and 12 years for pc-Si. The levelized cost of energy is 0.077€/kWh for mc-Si and 0.075€/kWh for pc-Si.	Elam im et al. 2018
7	2×5.4 kWp, Morocco	(mc-si, pc-si, a-si), p-si	Y_F (kwh/kwp/month) = 105 to 188 for combined, 58.8 to 192.6 for pc-si, CF = 20.2% for combined, 14.63% for pc-si, PR = 77 to 99% combined, 58 to 96% for pc-si. Conclusion: combined is better than use of p-si only.	Attarai et al. 2017

2.2 Impacts of PVGC on grid networks

There was presumed that incorporating photovoltaic systems into electric grids would be simple; however, as photovoltaic system penetration grew, energy providers started to face new issues, primarily due to the intermittency of solar energy; PV system production is immensely sensitive to environmental conditions such as illumination intensity and temperature. The performance of solar panels is harmed when dust accumulates on their surface. The current and power of solar cells are also reduced by dust concentration, wind velocity, and gloomy days. As a result, not only does the power system have to deal with uncontrollable demand, but it also needs to deal with uncontrollable generation (Tobnaghi, 2016).

A series of reports on Task V of the PV power systems (PVPS) implementing agreement have been released by the International Energy Agency (IEA). Investigations were conducted into islanding, capacity value, certification requirements, and demonstration project results, but the one that was most important in this case concerned voltage rise. This study looked at three different high-penetration PV configurations in the low-voltage distribution network: all PV on one feeder, PV dispersed over all feeders on an

MV/LV transformer, and PV installed on all MV/LV transformers on an MV ring. The greatest PV penetration, according to this study, “will be equal to whatever the minimum load on that specific feeder is. That minimum load was assumed to be 25% of the maximum load on the feeder, and if the PV penetration were 25% of the maximum load, then only insignificant overvoltages occurred. Any higher PV penetration level increased the overvoltages” (Eltawil and Zhao, 2010).

Asano et al., (1996) created a mathematical model to assess the impact of small rooftop PV power-generating stations on economic and performance variables in a larger-scale power system. They discovered that, compared to a normal system, an electrical power system with a 10% contribution from PV stations would require a 2.5% increase in load frequency control (LFC) capacity. For contribution levels of less than 10%, the break-even cost for PV power generation was determined to be relatively high. Higher PV power generation proportions resulted in reduced break-even prices, but economic and LFC considerations enforced a 10% top limit on PV contributions to overall power systems.

If a PV resource is integrated with other voltage-regulating devices and allowed to engage in reactive power control, most technical hurdles and operational problems can be resolved, and there will be no practical limits to how much PV resource the grid can host, paving the way for a sustainable power grid (Alboaouh and Mohagheghi, 2020).

CHAPTER THREE: RESEARCH METHODOLOGY

A research methodology is a comprehensive, conceptual assessment of the procedures used in a field of study.

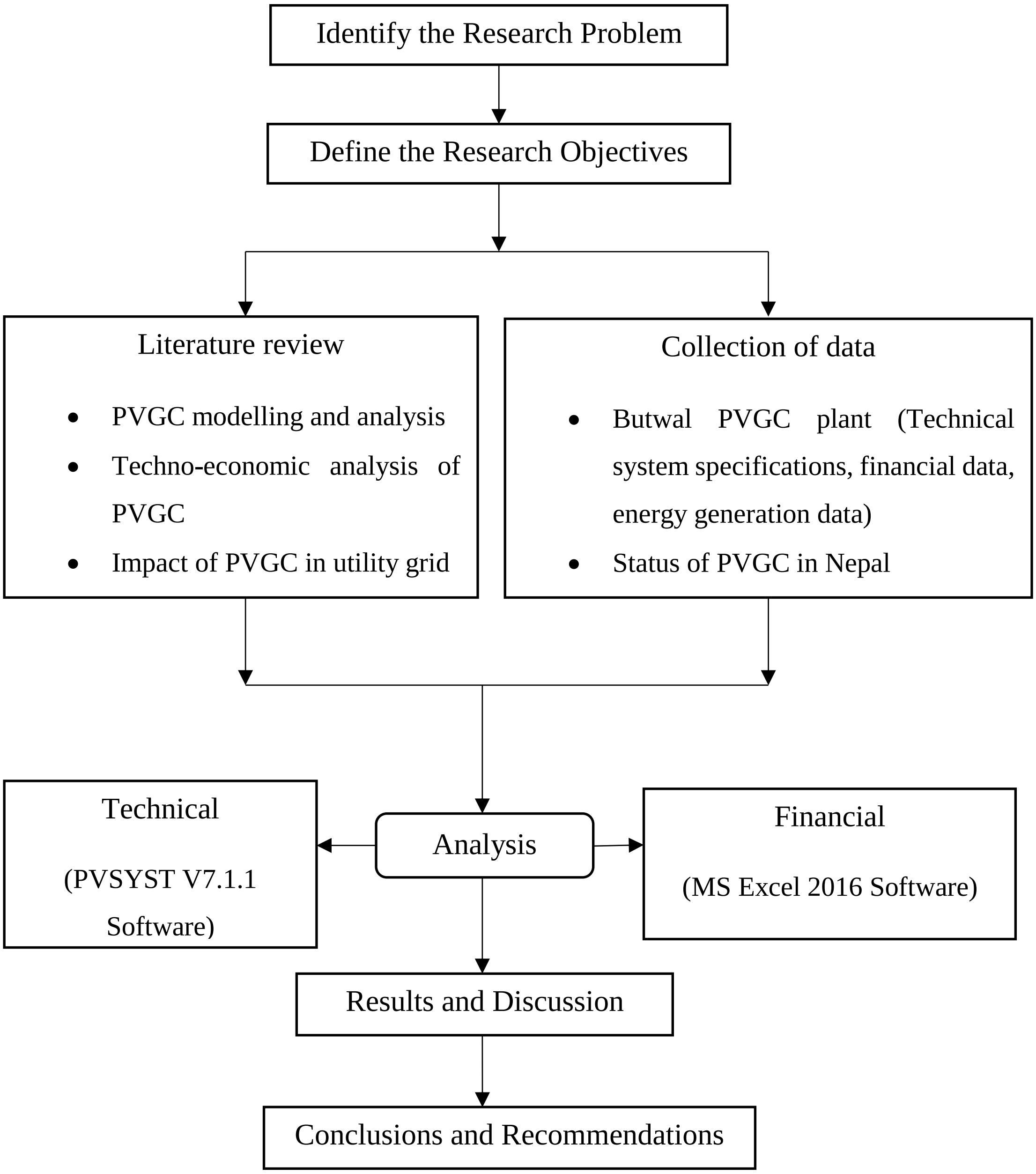


Figure 3.1 Framework for the study

The basic structure of methodology adopted in this thesis research work is as per figure 3.1 (Shiva Kumar and Sudhakar, 2015). After problem formulation and initial literature review, data required were collected and system configuration is developed on PVSYST to estimate the technical outcome. Financial outcome and sensitivity analysis was done in MS excel. After a comparison of technical performance conclusion and recommendation is drawn. A similar framework is used for confirming real-time monitored and the simulated PV performance (Manoj Kumar et al.,2019; Thotakura et al., 2020).

3.1 Data collection

Primary data is that which is collected by researchers themselves during their research using research tools such as experiments, survey questionnaires, interviews and observation. Data gathered by someone other than the primary user is referred to as secondary data.

Discussion about general project aspect was done with Ridi hydropower development company limited key person at Kathmandu head office. The site visit was done to overview the plant configuration. Net energy exported by the project is taken from the Butwal NEA grid office. The metrological data was obtained from the Solargis website, which was imported to PVSYST later for simulation purposes. Also, the Power Purchase Agreement (PPA) document between NEA and Ridi hydropower development company limited which was signed in September 2018 was collected from DoED. From the Department of Hydrology and Meteorology, solar radiation data of Bhairahawa Automatic Weather Station (AWS), which is nearly 15 Km west of PV Plant, was done. From 2020 November to 2021 September Pyranometer hourly kW/m^2 reading is obtained where some data are missing as well. Since the Pyranometer is installed in a horizontal position, for a tilted PV analysis from PVSYST it is found that insolation gain will be 11.3 %. Although the difference between Bhairahawa insolation data and that used on contract energy during PPA is 11% on annual value but the difference on monthly values are higher than that of between PPA and Solargis datasets. Because of missing radiation data and actual day length for accurate insolation calculation on a tilted surface, insolation data during PPA is used for analyzing the actual energy supplied to the grid and actual performance indicator.

3.1.1 System description

Butwal Solar Project is located at Lumbini province Tilottama-6, Nurserygram, Butwal Nepal receiving annual average insolation of 4.9 kWh/m^2 /day. Butwal is one of the major developing cities of Nepal which lies in the Terai plain area. Its elevation level is 150 masl. The climate in this region usually reaches scorching hot in summer whereas foggy cold in winter. The Salient Features of the project is shown in table 3.1.

Table 3.1 Salient features of the project

1. Project Location	
Province	Lumbini
District	Rupandehi
Municipality/ward	Tilottama-6, Nurserygram
Geographical Coordinate	
Latitude	27°37′42″ N to 27°38′08″ N
Longitude	83°27′05″ E to 83°27′23″ E
2. Meteorology	
Average annual Insolation	4.9 kWh/m^2 /day
Average annual Temperature	25°C
Average annual Relative Humidity	62%
Average annual Wind Speed	0.7 m/s
3. General	
Installed Capacity	10612.8 kW_p [DC] 8500 kVA [AC]
Contract Annual Energy	1,45,10,584 KWh
Transformer	8500 KVA (33/2×0.69 KV)
Transmission line	33 kV (5.6 km)
Rated Power frequency / grid voltage	50 Hz / 33 kV
Project Cost	NRs. 67.5 Crores
Construction period	2019/20

The overall plant single line diagram (SLD) is shown in fig 3.1 where similar ten inverters were fed from the different PV arrays. The three winding transformer having two input winding is connected with five inverters in each winding. Various protective control relay, switchgear is used to protect the transformer and to ensure proper quality power supply. The detailed DC and plant's overall single line diagram are attached to appendix B and appendix C respectively.

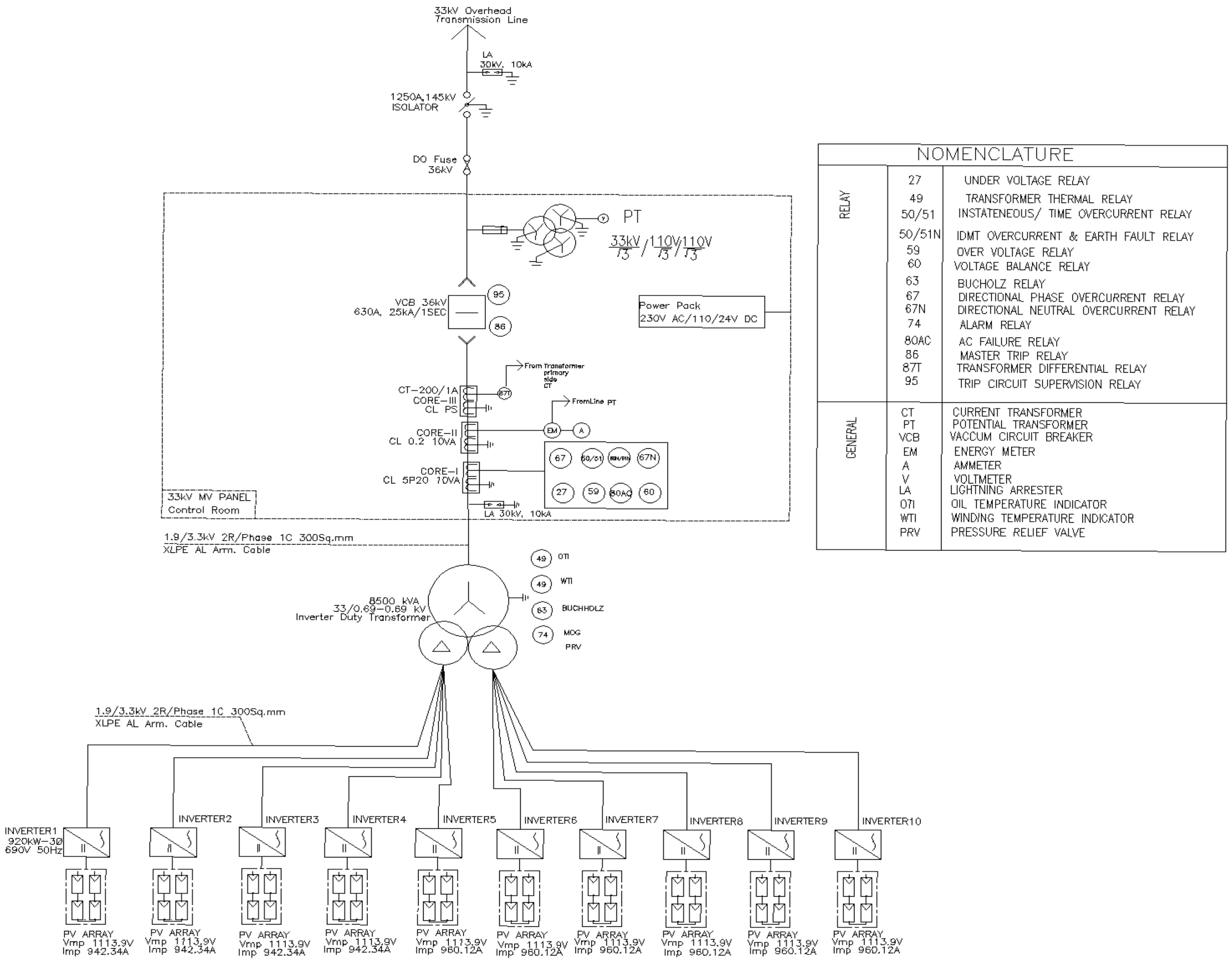


Figure 3.2 Single line diagram of Butwal solar plant

The electrical current, voltage and power level for different plant components are shown in table 3.2. Thirty PV modules were connected in series to form a string and 26 to 28 numbers of string were combined to feed the inverters. The output of the inverter and transformer shown in the table is based on the nominal ratings at unity power factor (UPF). The installation DC capacity of the plant is 10.6 MWp DC while the transformer nominal rating is 8.5 MW. This DC to AC ratio of 1.25 was chosen accounting for various array collection losses and other conversion process losses without having significant clipping loss. For utilization of the maximum power of 9200 kW that the inverter could produce, the transformer needs to operate with an overloading of about 8.2%.

Table 3.2 Electrical input and output levels for plant's components

Particulars	**Quantity**	**Parameter**	**Value**	**Total**
PV Modules in series to form string	30	Voltage (V_p)	37.13	1113.9
		Current (I_p)	8.89	8.89
		Power (W_p)	330.08	9902.57
PV strings DC input to Inverters (1,2,3,4)	1×28 + 3×26	Voltage (V_p)	1113.9	1113.9
		Current (I_p)	1×248.92 + 3×231.14	942.34
		Power (kW_p)	1×277.27 + 3×257.47	1049.67
PV strings DC input to Inverters (5,6,7,8,9,10)	2×28 + 2×26	Voltage (V_p)	1113.9	1113.9
		Current (I_p)	2×248.92 + 2×231.14	960.12
		Power(kW_p)	2×277.27 + 2×257.47	1069.48
Nominal AC output from inverters at UPF	10	Voltage (V_L)	690	690
		Current (I_L)	770	7700
		Power (kW)	920.24	9202.4
Input to transformer primary windings at UPF	2	Voltage (V_L)	690	690
		Current (I_L)	3850	7700
		Power (kW)	4601.2	9202.4
Nominal output from transformer secondary winding at UPF	1	Voltage (V_L)	33000	33000
		Current (I_L)	148.71	148.71
		Power (kW)	8500	8500

3.1.2 PV module

The solar module used was Polycrystalline Waaree Module, each rated 330Wp at STC. There are 32,160 identical solar modules used, thus comprising a system of a total capacity of 10.61 MWp. The detailed technical description is shown in table 3.3.

Table 3.3 Solar module specification

Particulars	Values
Manufacturer/Model/Technology	Waaree/WS-330/pc-Si
Country of origin	India
Rated Capacity	330 W_p
Voltage at maximum power (V_{mpp})	37.13 V
Current at maximum power (I_{mpp})	8.89 A
Open circuit Voltage (V_{oc})	45.95 V
Short circuit current (I_{sc})	9.57 A
Module Size (mm)	1960×990×40
No. of Modules	32160
Total Modules Area	62403 m^2
Efficiency	17.01%
NOCT	46°C (±2°C)
Temperature coefficient of P_{mpp}	-0.3859 %/°C
Temperature coefficient of Voc	-0.2775 %/°C
Temperature coefficient of Isc	0.0154 %/°C

As shown in figure 3.3, 30 modules were connected in series to form a string. The voltage becomes about 1114 V with this connection while the current is the same as that for a single module. Now, two strings are combined in parallel and the output is connected in SCB with a fuse in series. Here, 14 in one SCB is used as shown in figure 3.4. The output from such SCB is given to one of the MPP inputs of the inverter.

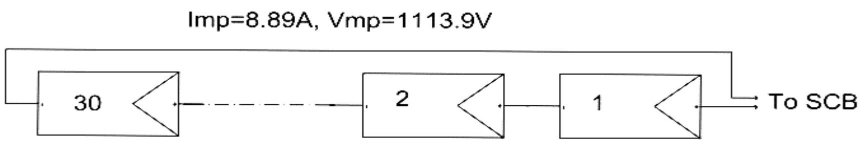


Figure 3.3 Modules connection in a String

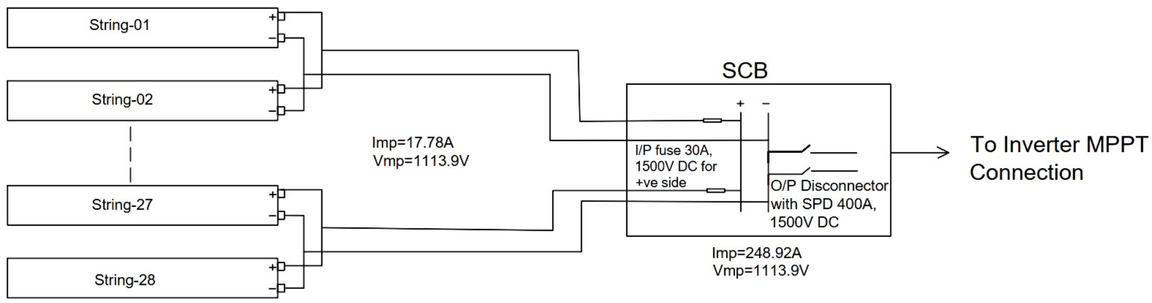


Figure 3.4 Strings connection to SCB

3.1.3 Inverter

Ten numbers of similar inverters each having a maximum output capacity of 920 kW were used. Table 3.4 shows the detailed specification of the inverter. It should be noted that output decreases with increasing temperature as the inverter output is rated for 840 kW at 50°C. Here, the inverters can be subdivided into two groups say group A and group B based on the PV array connection fed to it. All inverter utilizes their four MPP input units. As shown in figure 3.5 group A inverters i.e., inverters 1, 2, 3, 4 were fed with 1 input of 28 strings and the other 3 input with 26 strings. Similarly, in figure 3.6 group B inverters i.e., inverters 5, 6, 7, 8, 9 & 10 were fed with the first 2 inputs of 28 strings and the other 2 inputs with 26 strings.

Table 3.4 ON grid inverter specification

Particulars	**Values**
Manufacturer/Model	TMEIC/PVU-L0920ER
Country of origin	Japan
Rated Input Power (DC)	939 KWp
MPP Voltage Range	1005 V to 1300V
Maximum Input current	934 A
Rated Output Power at nominal AC voltage	920 kW @ 25°C 840 kW @ 50°C
Nominal AC voltage	3/PE, 690V (+10%,-12%)
Rated Output Current	770 A
Efficiency	98%

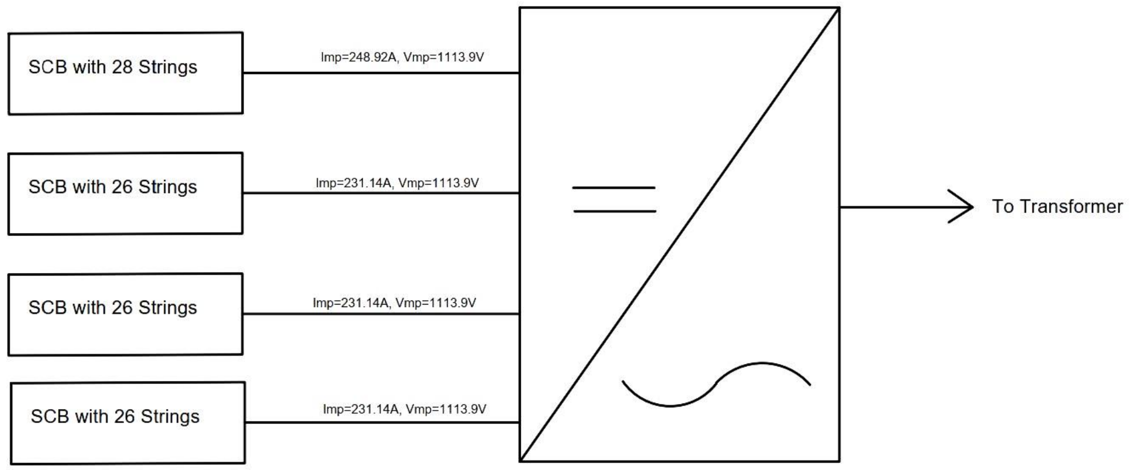


Figure 3.5 Group A inverter with array connection

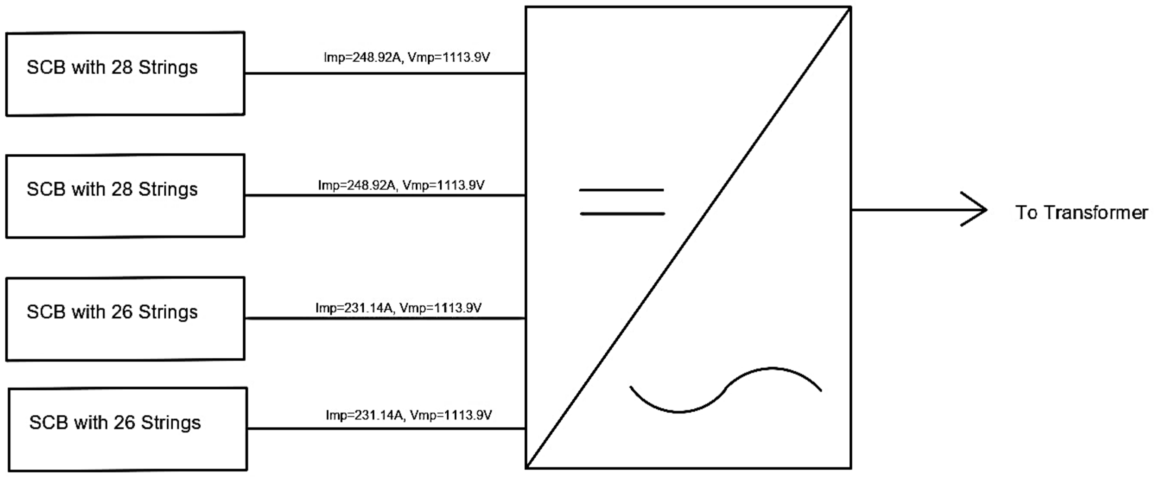


Figure 3.6 Group B inverter with array connection

3.1.4 Transformer

In this plant 3 phase Inverter duty transformer having NLTC features is used. It has 3 windings where the two primary windings each were connected to five inverters respectively as shown in figure 3.7. The use of an inverter duty transformer makes the solar plant system reliable and durable as these transformer windings are specially designed to withstand voltages excursions that arise due to inverter operation. Table 3.5 shows transformer specifications. Its rated capacity is 8.5 MVA with a voltage level of 33/2×0.69 kV. The oil natural air natural cooling indicates that it doesn't have high overloading capacity. Similarly, the no-load tap changer specifies that the tap position cannot be changed during operation for a quick response to voltage fluctuations.

Table 3.5 Transformer specification

Particulars	Values
Manufacturer/Type	Raychem RPG/Inverter Duty with NLTC
Country of origin	India
Capacity	8500 KVA
Voltage	33/2×0.69 kV
Current	148.71/2×3556.14 A
Vector group	YNd11d11
Impedance	6.58%
OFF Circuit tap changer	+7.5% to -7.5%, 2.5% steps
Type of Cooling	ONAN

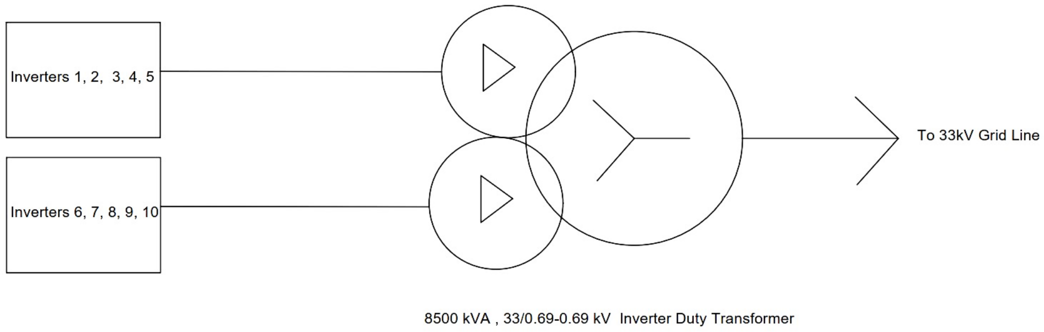


Figure 3.7 Transformer connection with inverters

3.1.5 Other accessories

a) Combiner Box

There were in total 40 combiner boxes, where the strings of PV modules are attached. Each inverter is fed with an output of four combiner boxes. The combiner box configuration is different for two groups of inverters.

Group A (Inverters 1 to 4): Three of the arrays consists of 780 PV modules with 26 strings in parallel and 30 modules connected in series and the other one array consists of 840 PV modules with 28 strings in parallel and 30 modules connected in series.

Group B (Inverters 5 to 10): First two of the arrays consists of 780 PV modules with 26 strings in parallel and 30 modules connected in series and the other two array consists of 840 PV modules with 28 strings in parallel and 30 modules connected in series.

b) Safety Provision:

i.Protection

Electrical protection ensures reliable and quality of service for system protection and power delivery. Here transformer and line protection use numbers of relays for various failure conditions. Some of the protection devices are listed in table 3.6.

Table 3.6 Protection devices

S.No.	Description	Protection Device	Rating
1	Array Combiner Box input side	Fuse	30A, 1500V
2	Array Combiner Box output side	Disconnector	400A, 1500V
3	Lightning Protection	Lightning Arrester	30kV, 10kA
4	Grid Interaction	Circuit Breaker	36kV, 630A, 25kA/1 sec
5	HV side maintenance	Isolator with earth switch	36kV, 400A

ii.Grounding

Grounding is done in an electric system to avoid risks during leakage of current. It is a connection of neutral of current carrying parts or non-current carrying part of metallic conductor to the ground or earth of infinite potential such that the surges or over-voltages or over-currents get properly discharged to the ground through low impedance path, reducing harm to the system and working personnel.

iii.Fire alarm

It is installed at the wall to detect fire conditions through thermal sensors and smoke sensors. Such devices warn people through alarm sound signals to minimize damage during emergencies. The authority is supposed to control the situation after alarm warns before the situation changes from bad to too worse. Carbon dioxide type fire extinguisher is made available in case of fire.

iv.CCTV

Closed Circuit Television (CCTV) is also used around the entry gate of the solar farm field and control room to view the real-time condition of the overall project area from the control room.

3.2 Performance parameters

The best technique to measure the potential for PV power production in a given location is to assess the performance of PV systems. The International Energy Agency (IEA) Photovoltaic Power Systems Program established parameters defining energy measures for PVGC systems, which are detailed in IEC standard 61724 (Marion et al., 2005). The performance of solar modules is usually measured in STC, which is not always representative of actual module operation. Sun tracker system, incident radiation, temperature, PV plant system technology and system efficiency all have an impact on a PV system's performance.

3.2.1 Specific yield

The specific yield (SY) is the ratio of energy generated per kWp installed capacity of the system.

$$SY = \frac{Annual\ Energy\ \ from\ the\ Plant(KWh)}{Plant\ Capacity(KWp)} \qquad \text{Equation 3.1}$$

It's commonly used to calculate the financial value of an array and compare operating results from different systems and technologies. It is also called total or final yield. Here the annual energy generated refers to the energy that is supplied at the AC grid side. The specific yield of a plant depends on:

- Irradiation falling on the collector plane.
- The performance of the module, including sensitivity to low irradiation levels and high temperatures.
- System losses including plant downtime.

Similarly, the array yield is the specific yield in terms of energy output on the PV array side i.e., DC energy output.

3.2.2 Capacity utilization factor

The capacity utilization factor (CUF) is the ratio of a solar plant's actual output over a year to the maximum achievable output under ideal operating conditions. The CUF typically ranges from 18 to 22 percent. Higher the capacity utilization factor lesser will be the cost of generated electricity (Shiva Kumar & Sudhakar, 2015).

$$CUF = \frac{Actual\ annual\ Energy\ from\ the\ Plant(KWh)}{Plant\ Capacity(KWp)*24*360} \qquad \text{Equation 3.2}$$

Also,

$$CUF = \frac{Peak\ sun\ hours/day}{24h/day} \qquad \text{Equation 3.3}$$

Thus, CUF depends on the location where the PV system is going to install.

3.2.3 Performance ratio

The Performance Ratio (PR) is used to assess the quality of an installation. It provides a baseline against which different types and sizes of PV systems can be compared. If a plant has a 70% performance ratio, it means that 30% of the energy generated by the PV panels is lost due to system losses. The PR is calculated as follows:

$$Annual\ PR = \frac{Actual\ reading\ of\ plant\ output\ in\ KWh\ per\ annum}{Ideal\ plant\ output\ in\ KWh\ per\ annum} \qquad \text{Equation 3.4}$$

Also, the PR is the ratio of Y_F and Y_R (Shiva Kumar & Sudhakar, 2015). By normalizing with respect to irradiance, it computes the overall effect of losses on the rated output due to: PV module temperature soiling or snow, incomplete use of irradiance by reflection from the module front surface, module mismatch, inverter inefficiency, wiring, and supplementary losses when converting from D.C. to A.C. power; component failures and system down-time.

$$PR = \frac{System\ Yield\ (Y_F)}{Reference\ Yield\ (Y_R)} \qquad \text{Equation 3.5}$$

The final PV system yield Y_F is the net energy output E divided by the nameplate D.C. power P_0 of the installed PV array. The units are hours or kWh/kW. (Thotakura et al., 2020).

$$Y_F = \frac{Net\ energy\ output\ (E)}{system\ Installed\ capacity(P_o)} \qquad \text{Equation 3.6}$$

It represents the number of hours the PV array would have to run at full power for the same amount of energy to be produced. The YF normalizes the energy produced in relation to the system size; as a result, it is a useful tool for comparing the energy produced by PV systems of various sizes.

The reference yield Y_R is the total in-plane irradiance H divided by the PV's reference irradiance G at STC.

$$Y_R = \frac{\text{Total in plane Irradiance (H)}}{\text{Reference Irradiance (G)}} \qquad \text{Equation 3.7}$$

It refers to the equivalent number of hours at the reference irradiance. If G equals 1 kW/m^2, then Y_R is the number of peak sun-hours or the solar radiation in units of kWh/m^2. The Y_R defines the solar radiation resource for the PV system It is influenced by the PV array's location, orientation, and weather variations from month to month and year to year.

The theoretical maximum value of PR is 100%, but due to various system losses, this number is never attained. This ratio determines a solar PV plant's efficiency and reliability. PR can reach a value of 80% in highly efficient plants.

Array capture losses (L_c) are due to the losses on PV array. While system losses (L_s) are due to DC into AC conversion by inverter including system down-time.

$$L_c = Y_R - Y_A \qquad \text{Equation 3.8}$$

$$L_s = Y_A - Y_F \qquad \text{Equation 3.9}$$

The determination of the PR at fixed regular intervals does not provide an absolute comparison. Instead, it allows the operator to evaluate the system's performance.

3.3 Factors affecting performance ratio

The performance ratio is a solely definition-based variable that, depending on the circumstances, can even exceed 100%. This is because the performance characteristics of PV modules are utilized in the calculation of the performance ratio, which was obtained under standard test settings of 1,000 W/m^2 solar irradiation and 25 °C module temperature. As a result, real-world operating conditions have an impact on PR. The following factors can influence the PR value (SMA solar, n.d.).

3.3.1 Environmental factors

a) The temperature of the PV module

A PV module is especially efficient at lower temperatures.

b) Solar irradiation and power dissipation

When the sun is low in the sky in the morning, evening, and especially in winter, the value for incident solar irradiation approaches that of power dissipation more closely than at other times of day and year As a result, the PR value is lower than usual during these times.

c) Measuring gage (sensor) in the shade or soiled

The partial or complete placing in the shadow of the measuring gauge can result in PR values of over 100 %.

d) Shading or contamination of the PV modules

Plants and structures can cast shadows on PV plants depending on the installation site. Dust, pollen, snow, and other contaminants can also cause PV modules to be shaded. As a result of the shading, the PV module absorbs less solar radiation than typical. The efficiency of the PV modules decreases, and the PR value of the PV plant reduces as a result.

3.3.2 Other factors

a) Measurement period

If the measurement period is too short like less than one month, there are insufficient measurements for reliable calculation of the performance ratio. Low solar elevations, low and high temperatures and shading influence the calculation result in this case more strongly, as these values may not be completely recorded.

b) System efficiency

The higher the efficiency of the PV modules, inverters, transformers and transmission lines the higher the PR value.

c) Use of different solar cell technologies in the PV modules and measuring gauge

If the PV plant's measuring gage employs a different solar cell technology than the plant's PV modules, this can cause performance ratio discrepancies. Similarly, if a PV plant has a measuring gauge that is not appropriately aligned with the PV modules in the plant, variable solar irradiations can result in PV values of above 100%.

3.4 Reason to choose PVSYST

PVSYST is a computer simulation program for studying, classifying, and analyzing solar photovoltaic systems in their entirety. This program can handle stand-alone, solar lift and grid connected solar photovoltaic systems. With just a few system variables, the PVSYST program can calculate monthly PV system yields, load profiles, and predicted system costs. The user can run different simulation iterations within the framework and compare the results to existing values. The PV Syst tool allows users to establish more comprehensive system parameters and examine light impacts such as mismatch and incidence angle losses, thermal behaviour, module quality, partial shadings of nearby objects on the array and wiring cable loss. The results provide lots of simulation variables, which can be displayed in hourly, daily or monthly values and can be exported to other software (Thotakura et al., 2020).

3.5 Simulation using PVSYST

The system was designed in detail in PVSYST and thus simulated. In this software, the database regarding panels, inverters and inverters of a different manufacturer is available. But Indian manufacturer waaree solar PV database wasn't there. So, firstly database was created for waaree panel WS-300 and TMEIC PVU-L0920ER and the string-array arrangement of system layout was given in the input panel. Detailed modelling was done with this software to evaluate the performance capacity of solar PV Panels.

3.5.1 Site information

The site location was given with coordinates 27.633099° N, 83.452368° E. The irradiance data was imported from solargis and the system azimuth was 0^0 and the tilt angle was 23^0.

3.5.2 PV modules

The system consisted of 4 sub-arrays of PV panels for each inverter. Hence 40 arrays consist of a various number of parallel strings comprising of 30 panels in series as listed in table 3.7.

Table 3.7 String configuration for inverters

Inverters	Arrays	Modules in Series (N_s)	Parallel Strings (N_p)	Total Modules (N_sxN_p)	Ratings (kW_p)
1 to 4	1	30	28	840	277.2
	2	30	26	780	257.4
	3	30	26	780	257.4
	4	30	26	780	257.4
5 to 10	1	30	28	840	277.2
	2	30	28	840	277.2
	3	30	26	780	257.4
	4	30	26	780	257.4

3.5.3 Inverter data

The total capacity of inverters is 9200 kW with ten identical 920 kW inverters of model PVU-L0920ER. Each inverter has four MTTP inputs with an input voltage range of 1005-1300V DC.

3.6 Impact of PVGC on the national grid network

It is important to remark that the impression of PV is network and location dependent. The Butwal Solar PV Plant is connected to NEA's Amuwa Distribution Centre through a 5.6 km 33 kV transmission line. The Amuwa substation is connected to the INPS grid through a 132 kV transmission line and feeds seven different feeders as shown in figure 3.8. Since the input of two transformers and delivery point of the plant is common at 33 kV busbar, the Butwal solar plant's generated power can flow to those various six feeders feed by two 33/11 kV transformers according to their demand and other excess power to INPS through a 132 kV transmission line. The plant's generation is nearly consumed in feeders supply through Amuwa substation except during mid-day when generation power is at peak around 2 MW of power exported to 132 kV line.

Since the power quality of INPS is poor, the plant had experienced some difficulties during the initial few days of testing as the voltage level goes beyond the standard limit up to 24 kV. After adjusting the inverters and relays voltage threshold level the plant becomes stable with the grid connection. The average monthly energy loss is around 3.7% due to line tripping and grid unavailability. The plant cannot operate in isolation mode.

Since the plant size is small compared to the national grid capacity. The fluctuation in power level due to the PV plant is easily handled by a 63 MVA transformer which is connected to the 132 kV national grid.

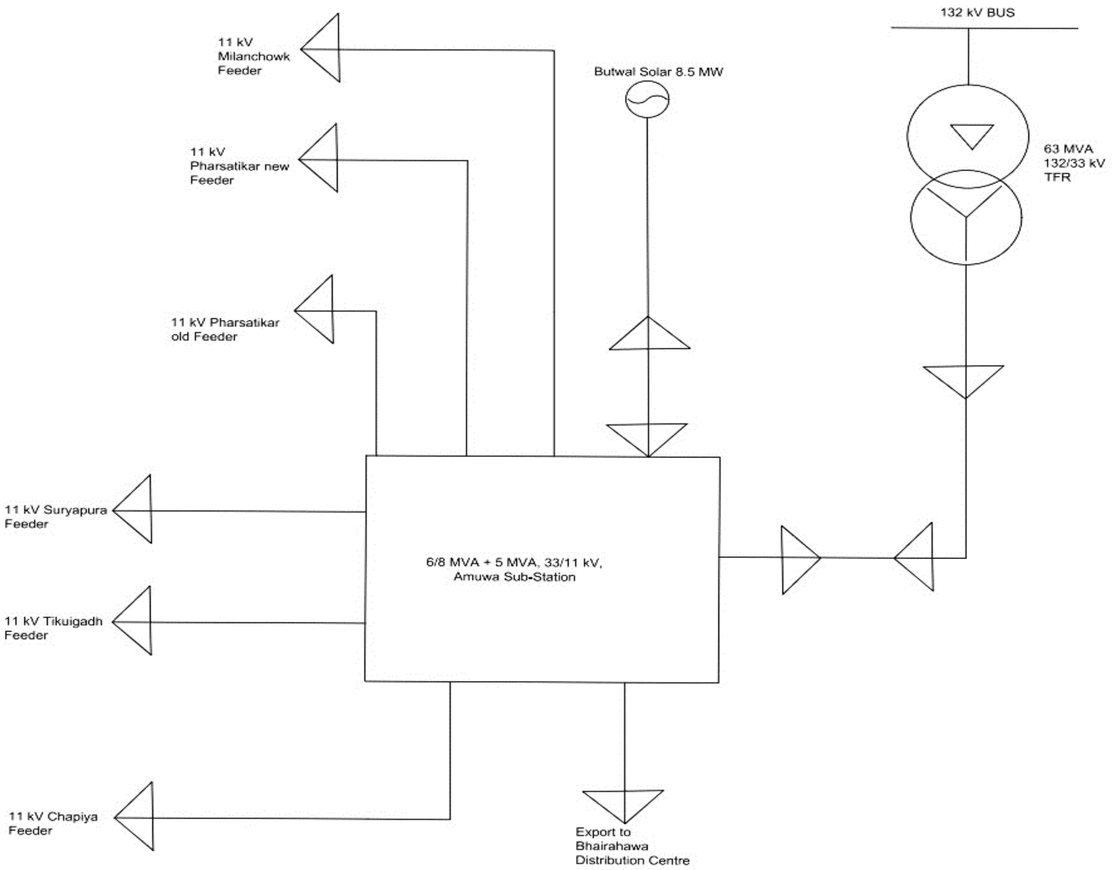


Figure 3.8 Block diagram of Amuwa distribution centre

Table 3.8 shows a day record of voltage, current and power factor at the side of the 33 kV incomer breaker. It can be seen that the grid voltage level is about 32.15 kV during the night and early morning (from 6 PM to 6 AM) while it is about 30.5 kV from 7 AM to 5 PM when the solar plant is active. Similarly, the grid average power factor gradually decreases from 0.9 to around 0.45 during power injection from the solar plant.

Although the power flow from the solar plant forces grid active power to be limited but not reactive power. At some time, when the needs of substation demand are exceeded by solar plant generation as in time 14:00 in the table, the power is exported to the grid 132 kV line.

The power flow from this plant seems to have a negative impact on the injected 33 kV substation and system voltage level, as there is a substantial drop in power factor and a slight voltage dip in that 33 kV substation.

Table 3.8 Electrical Reading at 33 kV incoming side of Amuwa substation

Reading time	**Current**	**Voltage**	**Power Factor**	**Active power**	**Reactive power**
	(A)	**(kV)**		**MW**	**MVAr**
1:00	74	32.57	0.94	3.92	1.42
2:00	74	32.58	0.94	3.93	1.42
3:00	74	32.58	0.94	3.93	1.42
4:00	73	32	0.96	3.88	1.13
5:00	73	32.85	0.94	3.90	1.42
6:00	80	32.31	0.93	4.16	1.65
7:00	82	30.26	0.89	3.83	1.96
8:00	70	30.62	0.69	2.56	2.69
9:00	68	29.3	0.33	1.14	3.26
10:00	66	31.08	0.21	0.75	3.47
11:00	68	31.32	0.35	1.29	3.46
12:00	72	31.4	0.43	1.68	3.54
13:00	69	30.62	0.33	1.21	3.45
14:00	66	30.27	0.00	0.00	3.46
15:00	64	30.28	0.25	0.84	3.25
16:00	88	30.16	0.68	3.13	3.37
17:00	103	29.95	0.79	4.22	3.28
18:00	109	31.85	0.85	5.11	3.17
19:00	104	31.31	0.94	5.30	1.92
20:00	99	32.85	0.95	5.35	1.76
21:00	99	32.6	0.9	5.03	2.44
22:00	87	32.4	0.9	4.39	2.13
23:00	83	31	0.9	4.01	1.94
24:00	80	31	0.9	3.87	1.87

The maximum permissible penetration level for photovoltaic power in a grid network is determined by the network's characteristics, as well as the locations, geographic distribution and types of PV systems inside the network (Tobnaghi, 2016).

There have been few numbers of solar power plants that are connected to the grid and getting paid through the net metering principle as shown in table 3.9 (Adhikari, 2020).

Table 3.10 listed the PV plants that have signed PPA with NEA where some are in operation and others are in the developing phase. The total installed capacity of grid connected solar PV is 39.08 MW while other projects with a total capacity of 65 MW that have signed PPA are in different stages of development.

Table 3.9 PVGC on net metering Scheme

S. No.	Plant Name	Capacity (kW)
1	Singh Durbar solar power plant	1000
2	Sundharighat	680
3	Kharipati, NEA	100
4	Sundhara, Nepal Telecom	65
5	Pulchowk, CES IOE	1
6	Kirtipur, Rara hill memorial school	40
7	Khumaltar, ICIMOD	53
8	Dhobighat, KUKL	680.4
Total		**2619.4**

Also, the Investment Board of Nepal (IBN) have been screening two large scale PVGC projects of a cumulative 800 MW. According to DoED, till January 2022 for the solar project; 118 MW of construction license, 624 MW of survey license has been issued and applications are pending for other 948 MW solar projects.

The plants which are in operation and at different stages of development is located in various places make diverse penetration levels of PV in the national grid network throughout the network area. Also, the majority of PV plants ' installed capacity is below 10 MW which makes less disturbance in the grid network during fluctuation in a generation.

There is no agreed-upon maximum permitted penetration limit for PV electricity in a network system. Depending on the limiting factor, as well as the size, placement, and geographic distribution of PV arrays results in the literature range from 1.3% to 40%. A complete techno-economic assessment should be conducted for each network in order to estimate the maximum permissible PV penetration.

Table 3.10 NEA and IPPs' solar projects

S. No.	**Plant Name**	**Capacity (KW)**
A	**In operation**	
1	Bishnu Priya Solar Farm Project, Nawalparasi	960
2	Butwal Solar Project, Rupandehi	8500
3	Mithila Solar PV Electric Project, Dhanusha	10000
4	Nuwakot solar project, Trishuli (17 MW out of 25 MW)	17000
Total		**36460**
B	**PPA signed (Different stages of development)**	
1	Belchautara Solar Project, Tanahun	5000
2	Chandranigahpur Solar Project, Rautahat	4000
3	Parwanipur Solar Project, Parsa	8000
4	Dhalkebar Solar Project - I, Dhanusha	1000
5	Simara Solar Project, Bara	1000
6	Dhalkebar Solar Project - II, Dhanusha	3000
7	Lamahi Solar Project, Dang	3000
8	Duhabi Solar Project, Sunsari	8000
9	Shivapur Solar Project, Kapilvastu	8000
10	Pokhara Solar Project, Kaski	4000
11	Parsa Solar Project, Jhapa	2000
12	Buluchowk Solar Project, Rautahat	5000
13	Gandak Solar Project, Nawalparasi	5000
14	Nuwakot solar project, Trishuli (8 MW out of 25 MW)	8000
Total		**65000**

As the numbers of the large-scale PV systems become high following impacts on transmission/sub-transmission networks can be seen (ElNozahy and Salama, 2013).

3.6.1 Severe power, frequency, and voltage fluctuations

Reactive power fluctuations cause significant voltage changes, whereas active power fluctuations cause severe frequency variations in the electrical network. During cloud transients, voltage flickers are more common at the growing penetration of PV systems.

3.6.2 Increased ancillary services requirements

Before voltage and frequency variations surpass the allowed limitations, utilities must add rapid ramping power generation to compensate for power fluctuations from PV plants. Current regulating generation sources, such as hydroelectric plants, are slower to adapt to rapid power variations.

3.6.3 Stability problems

As the penetration of PV rises, more conventional generators are being replaced by PV arrays, increasing the system's damping ratio. As a result, the system's oscillation reduces. The existence of solar PV generation can also alter the inter-area mode shape for synchronous generators that aren't replaced by PV systems. To maintain enough damping of the system, some key synchronous generators should be kept available, even if they are running outside their economic operating range. PV inverters working in the constant power factor mode degrade voltage stability, but PV inverters operating in the voltage control mode may increase system voltage stability.

3.7 Financial parameters

When a company uses its capital, such as cash on hand, stock sales, or retained earnings, it is referred to as equity financing. Individuals can fund their accounts with their own money, savings, or investments. When a company uses debt financing, it borrows money from outside sources and pays back the principal and interest on a set timetable. Bonds, loans, mortgages, venture capital pools, and a variety of other sources of debt capital are all potential sources of debt capital. Individuals can also use debt sources like credit cards and bank accounts. Combinations of debt-equity financing mean a Weighted Average Cost of Capital (WACC) result. WACC is a cost of capital measure in which each capital component is proportionally treated.

$$\mathrm{WACC} = \frac{K}{K+G}(r_k) + \frac{G}{K+G}(r_g)(1-T) \qquad \text{Equation 3.10}$$

Where:

K = Market value of the firm’s equity

G = Market value of the firm’s debt

r_k = Cost of equity

r_g = Cost of debt

T = Corporate tax rate

A measure of worth is a criterion used in the engineering economy to choose an option for a set of estimations. All of these measures of worth consider the fact that money has a time value. (Pandey, 2015).

3.7.1 Net present value

Net Present Value (NPV) is the difference between the present value of cash inflows and outflows over a certain period. NPV is used in investment planning to examine the viability of a projected outlay (Elamim et al., 2019; Elamim et al., 2018).

$$NPV = \sum_{t=1}^{n} \frac{B_t}{(1+i)^t} \quad \text{Equation 3.11}$$

Where:

B_t = Net cash inflow during a period t

i = Discount rate

t = Number of times periods

3.7.2 Internal rate of return

The Internal Rate of Return (IRR) is a discount rate which gives the NPV of zero for estimated future series of cash flows. An investment with a greater internal rate of return is more favorable to execute.

$$\sum_{t=1}^{n} \frac{B_t}{(1+IRR)^t} - B_o = 0 \quad \text{Equation 3.12}$$

Where:

B_t = Net cash inflow during a period t

B_o = Total initial investment costs

IRR = The internal rate of return

t = Number of times periods

In planning investment projects, firms will often create a Minimum Attractive Rate of Return (MARR) to determine the minimum acceptable return. The MARR will be higher than the WACC (Park, 2012).

3.7.3 Payback period

The payback period is an estimated time for the revenue saving & other monetary benefits to completely recover the initial investment plus a stated rate of return. If recovery of only the initial investment is considered then it is called the Simple Payback Period. While in Discounted Payback certain return in addition to recovering the initial investment is considered (Abdalla & Özcan, 2021; Ibrik, 2020).

$$\text{Payback Period} = \frac{\text{Initial investment}}{\text{Net Cash Inflow per year}} \qquad \text{Equation 3.13}$$

The discounted payback period is often used to better account for some of the shortcomings such as using the present value of future cash flows. As a result, the basic payback period may be beneficial, whereas the discounted payback period may imply a risky investment.

3.7.4 Debt service coverage ratio

The Debt-Service Coverage Ratio (DSCR) is a measurement of a firm's available cash flow to pay current debt obligations. The DSCR informs investors about a company's ability to pay its debts. (Pandey, 2015).

$$\text{DSCR} = \frac{\text{Net Operating Income}}{\text{Total Debt Service}} \qquad \text{Equation 3.14}$$

The DSCR will be determined by the industry, rivals, and stage of development of the company. For example, a smaller company that is just starting to generate cash flow may have lower DSCR expectations than a mature, well-established corporation. A DSCR exceeding 1.25 is frequently seen as strong, whilst ratios below 1 may suggest that the company is experiencing financial troubles.

3.7.5 Levelized cost of energy

The Levelized Cost of Energy (LCOE is the ratio of NPV of cost to NPV of energy produced over the lifetime of the plant. The LCOE can be thought of as the average minimum price at which the asset's power must be sold to cover its total production expenses over its lifetime (Elamim et al., 2019).

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{P_t + M_t + F_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}} \quad \text{Equation 3.15}$$

Where,

P_t = capital investments made in year t

M_t = annual maintenance and operating costs for year t

F_t = fuel costs for year t

E_t = amount of electricity generated in year t

n = expected life of the facility

i = discount rate

The LCOE is frequently used by financial analysts to assess different energy-producing technologies, such as hydro, thermal, nuclear solar and wind power. It enables these comparisons even though the projects have different life spans, different capital prices, different project sizes, and different risk levels. This is because the LCOE indicates the cost of electricity generated per unit, and the risk of each project is determined by the discount rate applied for each power-generating plant.

3.8 Financial analysis

The NEA and the Ridi hydropower company entered a 25-year power purchase agreement (PPA) at a rate of Rs 7.30 per unit, with a guaranteed annual electricity supply of 14.5 million units. The project, which cost NRs 675 million, is expected to generate Rs 100 million every year. According to a company representative, the project was built with a 70% loan and 30% equity investment. Bank of Kathmandu, Citizens Bank, and Nepal Bangladesh Bank had contributed to the loan. The 'Guidelines of Grid Connected Alternative Energy Development', which was enforced by the Ministry of Energy, Water Resources and Irrigation, has a fixed power purchase rate for power plants greater than 1 MW pricing not exceeding Rs 7.30 per unit making competition for PPA agreement. This rate of Rs 7.30 per unit has been fixed based on the annual PPA rate of the RoR hydropower plant raised by 3% per annum up to eight times. So, there will be no escalation of this PPA rate in the entire life of such an alternative power plant.

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 PVSYST simulation

PVSYST simulation summary is shown in figure 4.1

PVsyst V7.1.1
Simulation date:
24/03/21 11:18
with v7.1.1

Project: butwal 8.5mw with solar gis data

Variant: New simulation variant

Project summary

Geographical Site	Situation		Project settings	
Golkawa	Latitude	27.63 °N	Albedo	0.20
Nepal	Longitude	83.45 °E		
	Altitude	121 m		
	Time zone	UTC+5.8		

Meteo data
Tilottama
SolarGIS Monthly aver. , period not spec. - 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	23 / 0 °		

System information

PV Array		Inverters	
Nb. of modules	32160 units	Nb. of units	10 units
Pnom total	10.61 MWp	Pnom total	9200 kWac
		Pnom ratio	1.154

Results summary

Produced Energy	14064 MWh/year	Specific production	1325 kWh/kWp/year	Perf. Ratio PR	72.10 %

Figure 4.1 PVSYST simulation summary

4.1.1 Irradiance

The daily average estimated global tilted irradiation data for each month can be represented in figure 4.2. The variation of irradiance shows that it is highest in March-April and least in Dec-Jan. The average annual irradiation is found to be 5.04 $kWh/m^2/day$. In a day, the profile depicts varying power production patterns owing to weather and the PV system configuration chosen. This should be observed that the average yearly profile is a theoretical idea, as weather unpredictability causes profiles to be unique for each day of the year.

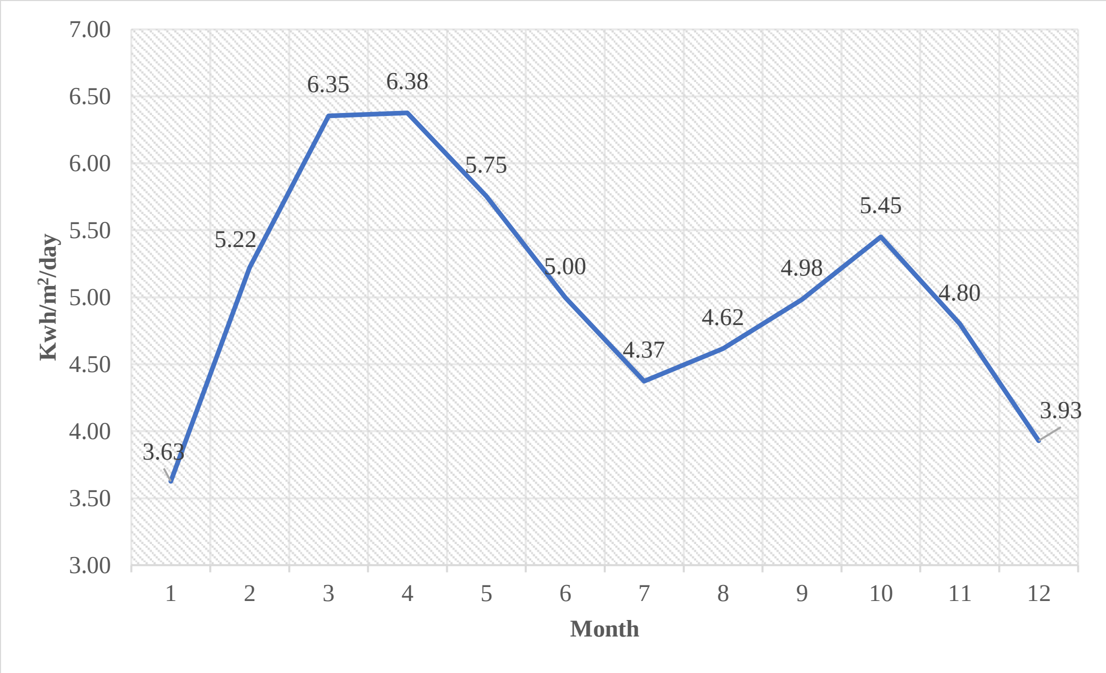


Figure 4.2 Variation of daily average global tilted irradiation throughout the year

4.1.2 Performance parameters

Table 4.1 Estimated monthly performance factors

Month	Tamb (°C)	GlobInc (kWh/m^2)	E_Grid (MWh)	specific energy yield (kWh/kWp)	PR (%)	CUF (%)
January	15	112.4	937	89.80	79	11.87
February	18.9	146.2	1091	115.80	70	15.30
March	24	197	1575	150.57	75	19.95
April	28.9	191.3	1447	138.42	71	18.94
May	30.7	178.4	1241	126.64	66	15.72
June	30.9	149.9	1092	104.78	69	14.29
July	29.5	135.6	1002	96.30	70	12.69
August	29.3	143.1	1078	103.37	71	13.65
September	28.6	149.5	1141	109.40	72	14.93
October	25.7	169	1344	128.34	75	17.02
November	21.2	144	1175	112.22	77	15.38
December	16.69	121.8	942	96.68	73	11.93
Annual	**24.95**	**1838.2**	**14065**	**1372.31**	**72**	**15.13**

Table 4.1 shows that specific yield varies from 89.80 (January) to 128.34 (October) with a yearly average of 1372.31 kWh\kWp. Similarly, the performance ratio varies from 79%

(January) to 66% (May). The yearly average capacity utilization factor is 15.13 %. It varies from 11.87 % to 19.95 %.

Table 4.1 selected data is shown in figure 4.3 to understand the consequence of temperature and irradiance on the energy output of the system. Even if there is a good amount of radiation the energy output decreases up to some range as a result of rising temperature.

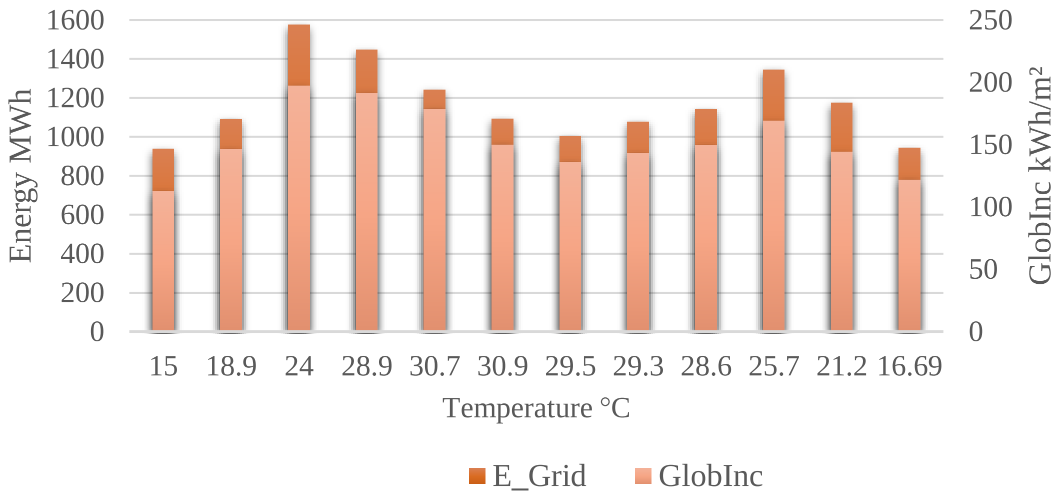


Figure 4.3 Monthly insolation vs. energy generated vs. temperature

4.1.3 Estimated generation in plant lifetime

Sankey diagrams are a kind of process flow in which the thickness of the arrows is proportional to the amount of energy produced, used, and lost. In PV systems losses occur due to irradiance level, soiling, conversion process, wiring and grid unavailability too. When doing a feasibility analysis for a large solar plant, performance deterioration and long-term ageing of PV modules and other system components must be taken into account. Figure 4.4 shows various losses that occur in the part of the system over a year. The majority of losses are due to soiling factor, irradiance level, temperature and inverter voltage threshold. The shading losses are neglected due to the free orientation of module structures. This gives the insight to reduce avoidable losses. For example, by increasing the MPP voltage range of the inverter 3% annual energy loss which accounts about 450 MWh, due to the inverter voltage threshold can be avoided.

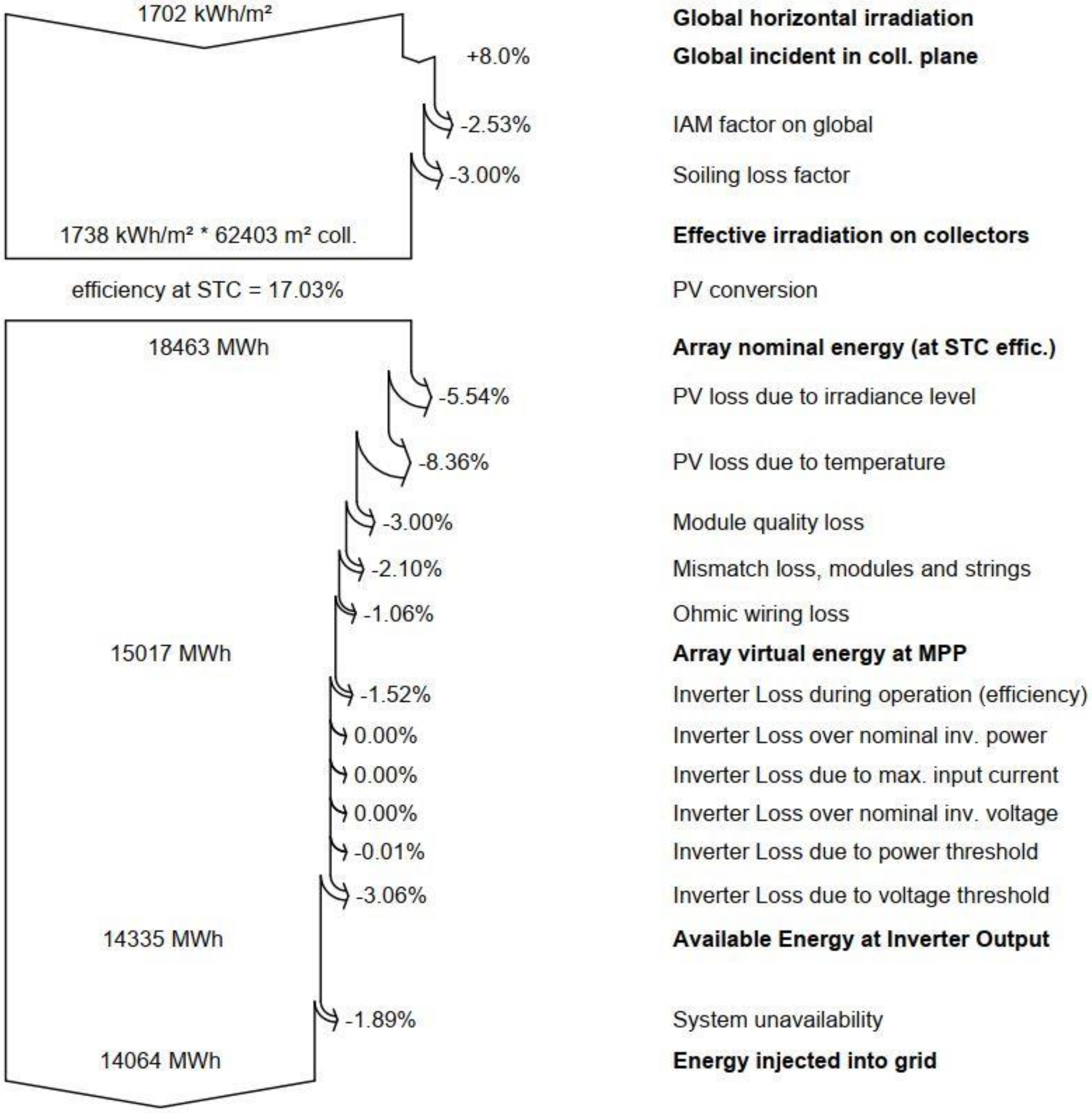


Figure 4.4 Sankey diagram for the entire year operation

One of the main purposes of an energy balance table is to reflect the relationships between the primary production of energy, its transformation, and final consumption. As shown in table 4.2 energy input of GTI 1838 kWh/m^2 produces specific energy output of 1738 kWh/kWp considering soiling, reflectivity and spectral correction. With consideration of conversion loss from solar radiation to electrical energy and technical availability of grid, the energy output becomes 14068 MWh.

Table 4.2 Energy conversion and related losses

Energy Conversion step	Input Energy Kwh/m²	Energy gain/ loss Kwh/m²	Energy output MWh	Energy yield Kwh/kwp	Energy loss/gain %
Theoretical GHI	1702	-			-
Loss due to horizon shading	1702	0			0
Particular site GHI	1702	0			0
Effective to surface of PV modules	1838	136			8.0
GTI	1838				
Dust, dirt and soiling	1783	-55			-3.00
Loss due to IAM factor	1738	-45			-2.53
Effective irradiation on modules	1738	-100			-5.53
Nominal array energy (at STC in 62403 m²)	1738		18469	1442	-17.03
Effectof irradiance level in PV			17446	1362	-5.54
Effect of temperature in PV			15987	1248	-8.36
Effect of module quality			15508	1211	-3.00
Modules, strings mismatch loss			15182	1185	-2.10
Effect of wire resistance			15021	1173	-1.06
Array Virtual energy at MPP			15021	1173	-20.06
Effect of inverer operation			14793	1155	-1.52
Effect of inverter power threshold			14791	1155	-0.01
Effect of Inverter Voltage threshold			14339	1119	-3.06
Available Energy at Inverter			14339	1119	-4.59
Effect of Grid Unavailability			14068	1098	-1.89

Since the plant module warranty period and PPA both were valid for 25 years so it can be assumed that the useful life of Butwal solar PV is 25 years. As shown in table 4.3 the plant degrades by 20% in 25 years of operation. This degradation is mainly considered solar panel ageing loss of 0.8% per year. The performance ratio indicates that a PV system's average efficiency over its lifetime is around 65%. The plant's average annual yield is 1,238 kWh\kWp. Generation over a lifetime is estimated at around 317 GWh with an annual value of 12.7 GWh.

Table 4.3 Plant electricity delivery over the lifetime

Year	Degradation rate	Final yield	E_grid	PR
	%	kwh/kwp	Kwh	%
Simulated	-	1,372.31	14,065,000.00	72.10
1	0.8	1,361.33	13,952,480.00	71.52
2	0.8	1,350.44	13,840,860.16	70.95
3	0.8	1,339.64	13,730,133.28	70.38
4	0.8	1,328.92	13,620,292.21	69.82
5	0.8	1,318.29	13,511,329.87	69.26
6	0.8	1,307.74	13,403,239.24	68.71
7	0.8	1,297.28	13,296,013.32	68.16
8	0.8	1,286.90	13,189,645.22	67.61
9	0.8	1,276.61	13,084,128.05	67.07
10	0.8	1,266.39	12,979,455.03	66.54
11	0.8	1,256.26	12,875,619.39	66.00
12	0.8	1,246.21	12,772,614.43	65.47
13	0.8	1,236.24	12,670,433.52	64.95
14	0.8	1,226.35	12,569,070.05	64.43
15	0.8	1,216.54	12,468,517.49	63.92
16	0.8	1,206.81	12,368,769.35	63.40
17	0.8	1,197.16	12,269,819.20	62.90
18	0.8	1,187.58	12,171,660.64	62.39
19	0.8	1,178.08	12,074,287.36	61.90
20	0.8	1,168.65	11,977,693.06	61.40
21	0.8	1,159.30	11,881,871.51	60.91
22	0.8	1,150.03	11,786,816.54	60.42
23	0.8	1,140.83	11,692,522.01	59.94
24	0.8	1,131.70	11,598,981.83	59.46
25	0.8	1,122.65	11,506,189.98	58.98
Average	**0.8**	**1,238.32**	**12,691,697.71**	**65.06**
Commulative	**20**	**-**	**317,292,442.74**	**-**

4.2 Carbon emission balance

The lifecycle emissions of the plant and its detail are shown in Table 4.4. The saved CO_2 savings with time which is shown in Figure 4.5 is extracted from the PVSYST simulation report where the CO_2 emissions balance is estimated over a lifetime of 25years for the grid-connected PV plant system. From the simulation, it is found that the total energy injected into the grid is 317,292,442.74 kWh in 25 years of operation. The total CO_2 emissions produced are 18,186 tons including production, operation, maintenance and disposal of the plant's components. The replaced emissions based on energy generation are 952 tons because Nepal's grid-connected energy source emissions are only 3 gCO_2/kWh as the main sources are hydropower (IEA, 2010; PVSYST, n.d.).

It must be noticed that the average carbon intensity of electricity produced in the world was 475 gCO_2/kWh in 2018. If this level of emission is considered then for an average annual generation of 12.7 GWh in the project life cycle, annually 6,054 tons of CO_2 emission is avoided (IEA, 2019).

Table 4.4 Lifecycle emission balance

Generated emissions	LCE	Unit	Quantity	Subtotal $KgCO_2$
Modules	1713	$KgCO_2$/kWp	10,613	18,180,069
Supports	0.02	$KgCO_2$/kg	321,600	6,432
Inverters	1.98	$KgCO_2$/units	10	19.8
Total generated emissions				**(18,186,520.80)**
Replaced emissions for 25 years	3	gCO_2/kWh	317,292,442.74	**951,877.33**
Net CO_2 emission balance				**(17,234,643.47)**

The Government of Nepal had signed an agreement with the World Bank on February 24, 2021, which will provide up to US$45 million in support of Nepal's plans to cut carbon emissions caused by forest degradation and deforestation by 2025. Nepal will earn $5 per tonne of carbon dioxide emissions reduction. Nepal must either reduce emissions or enhance carbon stock in the forest to receive revenue. In order to reduce carbon emissions from traditional firewood, the government is seeking to promote the use of alternative energy sources. Based on this agreement, it can be estimated that for avoiding emissions of about 952 tCO_2 with the support of the Butwal solar plant an additional benefit of $4,760 can be earned from the carbon trade (Mandal, 2021).

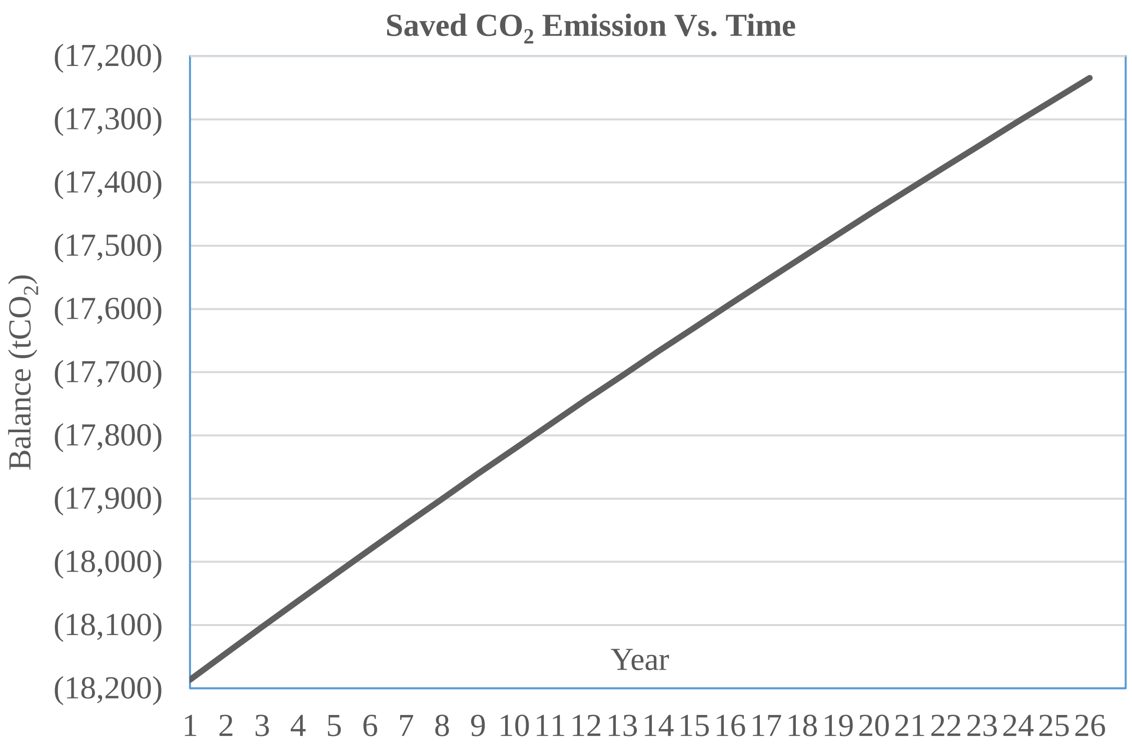


Figure 4.5 Carbon-dioxide emission balance

4.3 Actual energy generation and performance indicators

The plant had started its test generation from mid of Nepali month Asoj 2077 BS. So, from the month of Kartik year 2077 to the end of Asoj 2078 BS, the performance indicator table 4.5 is developed. It shows that plant is generating less than that of simulated and contract energy except for the first month of operation “Kartik”. The average annual PR, CUF, Specific energy is found to be 0.64, 13 % and 1140 kWh/kWp respectively.

Figure 4.6 shows the contract energy between NEA and the Butwal Solar Power plant is nearly equal to that of the estimated value after simulation. Some differences as seen may be due to different metrological data sources and loss calculations under study. With a difference of 3.07% in a year value, the results of estimated energy to the grid (Egrid) using PVsyst software are quite near to the contract energy. The actual generation for the first year of operation is found to be 13.95% and 16.59% less than those of estimated and contract values respectively. It can be seen that contract energy for the month of Baisakh, Jestha and Asar was assumed relatively high than the actual generation and PVSYST estimation.

Table 4.5 Performance parameter based on actual energy injected to grid

Month	Days	GlobInc kWh/m²	Simulated Energy MWh	Contract Energy Mwh	Actual Energy Exported to grid Mwh	Final Yield kWh/kW$_p$	PR %	CUF %
Kartik	30	134	1,260	1,089	1,183	111	83	15
Mangsir	29	119	1,059	964	887	84	70	12
Poush	30	116	940	939	741	70	60	9.7
Magh	29	121	1,014	977	754	71	59	10
Phalgun	30	157	1,333	1,269	1,033	97	62	13.5
Chaitra	30	183	1,511	1,483	1,210	114	62	15.8
Baisakh	31	192	1,344	1,562	1,226	115	60	15.5
Jestha	31	179	1,167	1,452	1,078	102	57	13.7
Ashadh	31	163	1,047	1,325	929	87	54	11.7
Shrawan	32	144	1,040	1,166	1,044	98	68	12.8
Bhadra	31	140	1,110	1,130	937	88	63	11.8
Ashwin	31	142	1,243	1,154	1,081	102	72	13.7
Annual		**1,790**	**14,065**	**14,511**	**12,103**	**1,140**	**64**	**13**

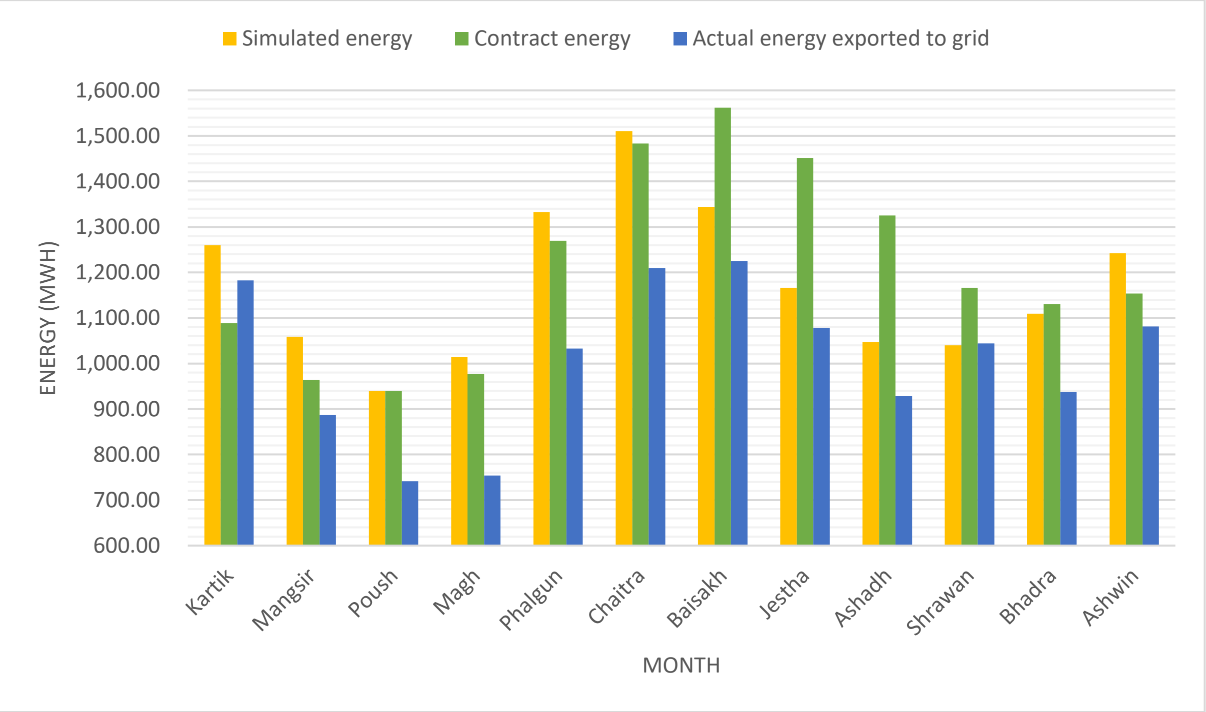


Figure 4.6 Comparisons of simulated, contract and actual energy exported to the grid

Table 4.6 shows normalised loss and Performance parameters for the first year of operation. It is assumed that array generation is 3.7% higher than actual energy exported to the grid corresponding to the average monthly energy loss that occurred due to grid unavailability as the plant couldn't operate on off-grid mode. The annual average collection loss (L_c), system loss (L_s) and final yield (Y_F) is found to be 1.69, 0.11 and 3.10 kwh/kwp/day respectively.

Table 4.6 Normalize loss and performance parameters

Month	**E_array**	**E_grid**	**Y_R**	**Y_A**	**Y_F**	**L_c**	**L_s**	**PF**	**CUF**
	MWh	**MWh**	**kWh/m² /day**	**kwh/kwp/day**				**%**	**%**
Kartik	1141	1100	4.48	3.58	3.46	0.90	0.13	14	77
Mangsir	920	887	4.11	2.99	2.88	1.12	0.11	12	70
Poush	769	741	3.87	2.41	2.33	1.46	0.09	10	60
Magh	782	754	4.16	2.54	2.45	1.62	0.09	10	59
Phalgun	1071	1032	5.22	3.36	3.24	1.86	0.12	14	62
Chaitra	1255	1210	6.10	3.94	3.80	2.16	0.14	16	62
Baisakh	1271	1226	6.20	3.86	3.73	2.34	0.14	16	60
Jestha	1118	1078	5.77	3.40	3.28	2.37	0.12	14	57
Ashadh	963	929	5.26	2.93	2.82	2.34	0.10	12	54
Shrawn	1083	1044	4.50	3.19	3.07	1.31	0.11	13	68
Bhadra	972	937	4.50	2.95	2.85	1.55	0.11	12	63
Asoj	1121	1081	4.59	3.41	3.29	1.18	0.12	14	72
Annual	**12465**	**12021**	**4.90**	**3.22**	**3.10**	**1.69**	**0.11**	**13**	**63**

4.4 Performance comparison

From the literature, primarily a few recent studies on similar grid-connected PV systems are included for comparison. Table 4.7 shows the comparison with current literature based on measures such as performance factor, yield factor, and capacity factor. The final yield (YF) normalizes the energy generated in relation to the system size, making it an ideal way to compare the energy produced by different-sized PV systems. The PV system in this study had an annual average daily final production of 3.1 kWh/kWp/day, which was greater than those reported in Khatkar-Kalan, India. It is similar to results from Serpong, Indonesia but lesser than the reported yields in Morocco, Andra Pradesh & Ramagundam - India.

Table 4.7 Performance comparison with existing literature

Location	KW_p	PV	Monitor Duration	Y_R	Y_A	Y_F	CUF	PR	Reference
				kWh/kWp/day			%	%	
Butwal, Nepal	10612	pc-si	Oct 2020-Sept 2021	4.9	3.22	3.1	13.00	64.20	This study
Serpong, Indonesia	10.6	pc-si	Jul 2019-Feb 2020	4.12	3.49	3.38	14.07	82.40	Nurdiana et al., 2020
Andra Pradesh, India	10000	pc-si	Oct 2018-Sept 2019	-	-	4.61	20.80	88.00	Thotakura et al., 2020
Morocco	2.04	mc-si	2015	-	-	5.17	21.56	80.66	Elamim et al., 2018
	2.04	pc-si		-	-	5.26	21.93	82.00	
Ramagundam, India	1000	pc-si	Apr 2014-Mar 2015	4.97	-	4.45	17.68	76.20	Kumar & Sudhakar, 2015
Khatkar-Kalan, India	190	pc-si	2011	2.91	-	2.15	9.27	74.00	Sharma & Chandel, 2013
Dublin, Ireland	1.72	mc-si	Nov 2008-Oct 2009	2.85	2.62	2.41	10.10	81.50	Ayompe et al., 2011

4.5 Financial results

The Butwal Solar PV project's basic financial related parameters and key results are shown in table 4.8. It is obtained from excel computation. For detailed financial results refer to appendix A.

An excel sheet is developed for basic financial and economic analysis where the debt tenure period is considered as 7 years with an interest rate of 11.98 %. Similarly, equity return is estimated to be 17 % and a discount rate of 11.81 % based on WACC. Annual operation and maintenance cost for the first year was assumed to be NPR 442.5 per kWp with cost escalating at 5.1 % thereafter every year based on Government Performance and Results Act (GPRA) operation and maintenance costs projected for 2020 for renewable technologies by NREL report 2010, multiplying with exchange rate averaging from October 2020 to September 2021, 1$ = NRs. 118. Energy degradation is taken as according to PV panel linear degradation of 0.8 % per year. As the Nepal government issues generation license for 25 years and the warranty for solar modules is also 25 years, the analysis period is considered accordingly.

Table 4.8 Financial parameters key input and output

Financial Parameter		Reference
Installed capacity (kWp)	10,612	RHDL, 2022
Annual contract energy (kWh)	14,510,583	PPA, 2018
Annual energy degradation	0.8 %	Waaree, n.d.
Project base cost (million NRs.)	675	RHDL, 2022
Project life time (years)	25	PPA, 2018
PPA rate (NRs.)	7.3	PPA, 2018
O&M cost (NRs. per KWp/year)	442.50	Tidball et al., 2010
Annual escalation on O&M	5.10 %	Statista, 2021
Interest rate	11.98 %	NRB, 2018
Tenure (years)	7.00	BoK, 2020
Debt	70.00 %	Bhusal, 2020
Debt amount (million NRs.)	472.50	-
Corporate income tax	20.00 %	IBN, 2020
Cost of equity	17.00 %	ERC, 2020
Equity	30.00 %	Bhusal, 2020
Equity amount (million NRs.)	202.50	-
Discount rate (WACC)	11.81 %	-
Key Results		
Project IRR	13.28 %	
Project NPV (million NRs.)	58.88	
Equity IRR	22.17%	
NPV of equity (million NRs.)	209.36	
Simple Payback (years)	6.9	
Discounted payback (years)	16.3	
Minimum DSCR	1.37	
Average DSCR	1.52	
LCOE (NRs./kWh)	6.70	

The positive values of NPV show that project outcome is financially beneficial. LCOE value is found to be 6.70 Rs/kWh which is slightly less than the tariff rate 7.3 Rs/kWh.

The net cumulative cash flow figure 4.7 shows the actual status of the project during its life period. It shows that the break-even period or simple payback period of the project is 6.9 years and cumulative cash value of NRs. 1,492 million at end of 25 years of operation.

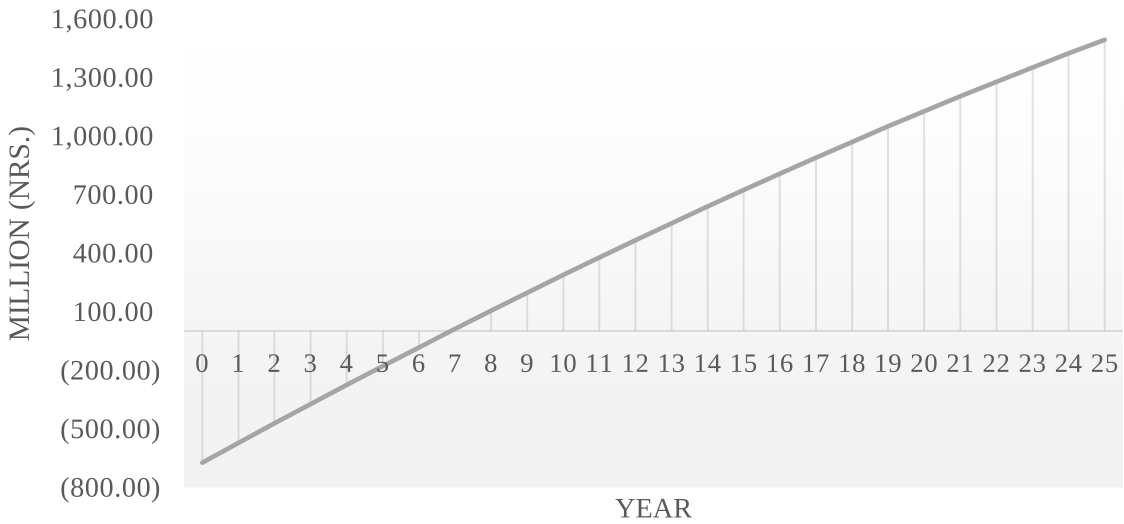


Figure 4.7 Cumulative cash flow over the project life

4.5.1 Sensitivity analysis

Since there are several uncertainties in the feasibility study about the future outcome of the project so, risk or sensitivity analysis must be done. The tornado diagram in figure 4.8 below shows that annual energy generation is more sensitive for the NPV of the project while degradation and operating maintenance cost nearly equal variation while changing these input parameter value ±20%. As the revenue is a product of energy generation and tariff rate, the variation of these two variables have the same effect on NPV outcome as given in table 4.9. Figure 4.8 shows the variation of NPV for different tariff rates. LCOE value of NRs. 6.7 is the tariff rate for which the NPV is zero. Similarly, an IRR of 13.28% is the discount rate for which the NPV is zero. Table 4.9 shows that project NPV is negative even if annual energy supplied to grid quoted in contract value decreases by 10 %. So, the plant engineers and energy company officials should focus to maintain the plant to decrease the losses in a generation to avoid financial loss from this project.

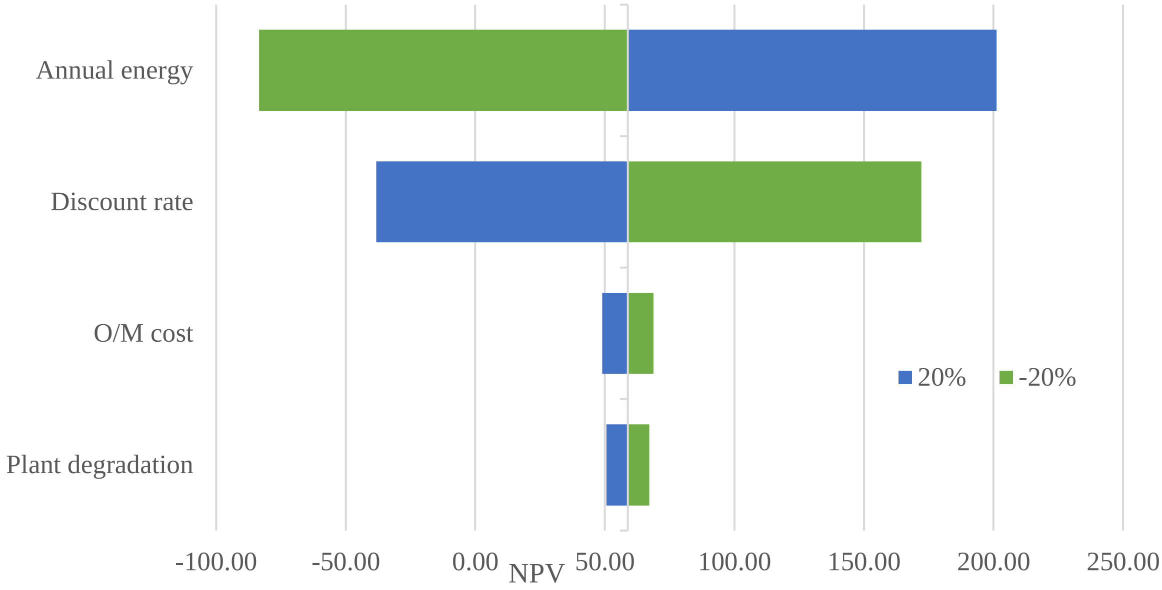


Figure 4.8 Tornado diagram for sensitive analysis result

Table 4.9 Sensitive analysis for project NPV

Sensitive Variables		**Multiplying factors to the base value**				
		0.8	**0.9**	**1**	**1.1**	**1.2**
Annual Energy Tariff Rate	MWh	11,608	13,060	14,511	15,962	17,413
	NRs	5.84	6.57	7.3	8.03	8.76
	NPV	-83.49	-12.31	58.88	130.10	201.25
Discount Rate	%	9.44	10.62	11.81	12.99	14.17
	NPV	181.41	115.23	58.88	10.6	-30.79
O&M Cost	Per kWp	354.00	398.25	442.50	486.75	531.00
	NPV	68.73	63.81	58.88	53.95	49.02
Plant Degradation	%	0.64	0.72	0.80	0.88	0.96
	NPV	67.11	63	58.88	54.76	50.65

Since the annual energy delivered from the plant to the grid depends on the average annual Global Horizontal Irradiance (GHI), table 4.10 shows the correspondence energy variation and performance ratio when the GHI is varied in the range of 80% to 119% of the base value of 1702 kWh/ m². The variation of ±20% is taken based on the global radiation variation from the least sunny year to the sunniest year reported in the research article (Skalik and Skalikova, 2019).

Table 4.10 Variation in GHI to evaluate energy delivery to grid

GlobHor	kWh/m²	1362	1447	1532	1617	1702	1787	1872	1958	2026
Annual Energy	MWh	10606	11510	12360	13174	14065	14904	15708	16467	17110
PR	%	69.9	70.8	71.3	71.5	72.1	72.4	72.6	72.7	72.9

Although, the tariff rate was fixed at rate of NRs. 7.3/kWh while signing PPA of this Butwal solar plant. The Nepal Electricity Authority just amended the PPA rate, proposing an upper ceiling rate of NRs. 5.94/kWh to the Electricity Regulatory Commission for implementation. This revision indicates that the bidders have to quote the solar energy tariff rate less than equal to NRs. 5.94/kWh for upcoming projects.

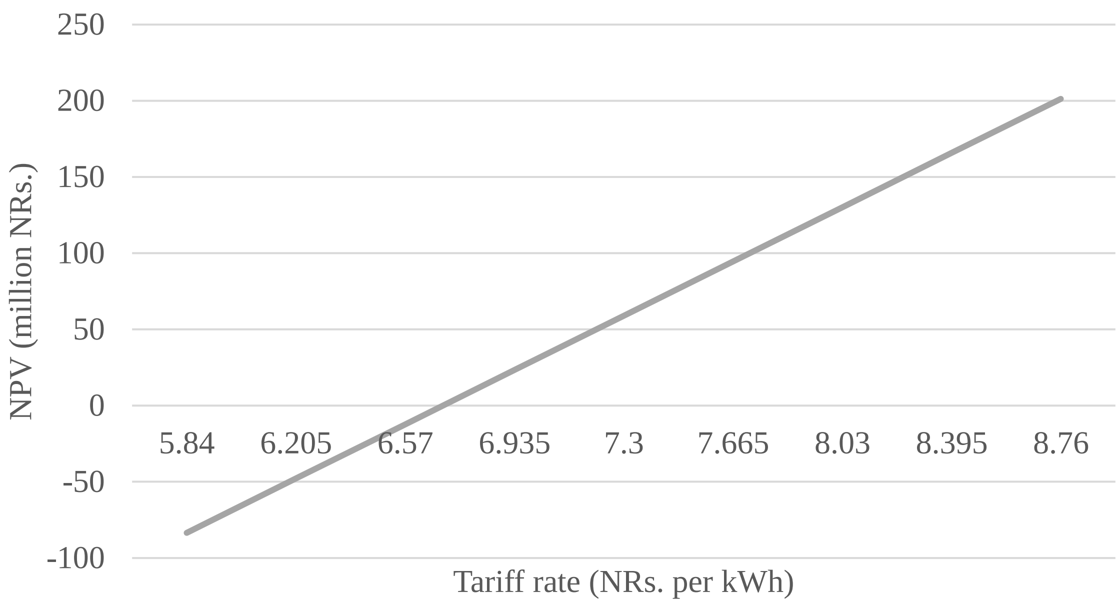


Figure 4.9 Plant NPV for different tariff rate

The Butwal Solar plant has an installed capacity of 10612 kW_p with a base cost of NRs. 67.5 crores specify the normalized cost of NRs. 63,607/kW_p. For the new proposed tariff rate of NRs. 5.94/kWh the project NPV is negative. If this project cost was about NRs. 593 crores then only proposed tariff rate of NRs. 5.94/kWh gives an NPV of zero. Thus, it suggests that new grid connected solar PV projects should have a base cost not more than NRs. 55,880/kW_p in order to be financially viable in the perspective of the Butwal solar PV project.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study provides a first-year operation performance including the estimated financial and technical outcome of 8.5 MW grid connected solar PV in Butwal, Nepal. The PVSYST simulated, PPA contract and actual monthly energy exported to the grid is found to be following a similar trend. As far as actual energy injected into the grid is compared to PVSYST results, the plant is closer to the expected generation of energy modelling software. During the study period, the discrepancy gap between estimated and measured values range from 0.4% in Shrawn 2077 B.S. to 19% in Mangsir 2078 B.S. The results demonstrate that what is predicted and what is generated are in accord, except for the months of Poush to Chaitra, when the error was considerable (20-34%), possibly due to differences in the irradiation data utilized in the simulations. The actual generation for the first installation month “Kartik” seems reasonably high due to less soiling loss owing to the recently installed solar module. As the month passes increased soiling loss decreased the energy output. In the winter months like Poush, Magh etc. due to fewer sunshine hours and foggy weather for several days’ effects on PV energy production. The annual daily average array yield is 4.25 kWh/m²/day at a reference yield of 4.90 kWh/m²/day. The final yield is 3.10 kWh/m²/day with a performance ratio of 64% and CUF of 13% respectively. Grid unavailability is also adding to system loss, as the plant has been operating and supplying electricity to the grid at an attainable percentage with almost 96.43%. Voltage variations and grid unavailability reveal that grid power quality and reliability are not fully sufficient for steady power flow. For a year, the system's actual energy delivery to the grid is 86% of the PVSYST estimate. This means that the PV module needs to be cleaned on a regular basis and grid interruptions should be minimized in order to get even more energy delivery. The simulation loss diagram result indicates that about 3% which account for about 450 MWh of annual energy is lost due to the inverter voltage threshold. This loss could have been omitted if the inverter had a wider MPP voltage range, especially in lower levels up to 900V was used. Also, the plant could have attained high performance if it had utilized a more efficient monocrystalline PV module having an efficiency of about 24%.

Financial analysis shows that plant would give a return of 13.28% with an NPV of NRs. 58.88 million. The LCOE value is found to be 6.7 NRs/kWh. A minimum DSCR value of 1.52 indicates good financing standing. Energy generation is the most sensitive parameter affecting the financial outcome. Besides generated energy revenue the project is also utilizing fertile land under PV panels by farming which will make an additional benefit. Since a carbon emission balance study reveals that around 952 tCO_2 will be replaced over the project's lifetime, it also supports the government's carbon trading.

The findings shed light on the solar PV power plant's long-term performance under real-world conditions in Nepal's Terai region. This PV system's results and operating knowledge can be used for upcoming solar PV projects.; for example, during a feasibility study of a solar PV project in the Nepal Terai region using PVSYST, it can be assumed that the actual annual energy generation could be below about 14% than that of the simulated result. Although the solar plant's power flow limits grid active power but not reactive power. The power flow from this plant seems to have a negative impact on the injected 33 kV substation and system voltage level, as there is a substantial drop in power factor and a slight voltage dip in that 33 kV substation. Based on the first-year results and projected future outcomes, it can be concluded that the 8.5 MW Butwal Solar PV plant will generate energy around the targeted value and will provide a proper financial return if the solar radiation value and other plant system operating performance are consistent with this study.

5.2 Recommendations

The Butwal solar PV plant's actual operation performance shows that it exhibits average performance. By analyzing the simulation result, it can be recommended that the plant could reduce energy loss due to the voltage threshold by increasing the MPP voltage range of the inverter.

Although the manual cleaning of the PV array is done on certain intervals of days, as the plant lies in the developing city of Nepal, the dust accommodation takes place within a day. As a result, it is advised that the module surface be cleaned more frequently. During daytime operation, the dry cleaning mechanism of the PV array can be adapted to profit from the maximum energy delivery to the grid. It is also suggested to do yearly testing of PV module sample installed at the site to find the degradation rate and check whether it meets the guaranteed efficiency.

NEA should maintain the high reliability of its grid network to full utilization of grid connected solar PV systems. The solar plant inverters' power factor should be set other than unity so that it helps to maintain grid reactive power, voltage level and good power factor. Also, to fix the contract energy during PPA signing with solar PV projects, it is recommended to use simulating software like PVSYST to evaluate the corresponding monthly energy generation throughout the year rather than using a simple calculation. PVSYST accounts for a non-linear loss like loss due to irradiance level effectively which is difficult to estimate in a simple calculation.

Installation of large-scale solar PV should consider proper land use by an alternative method like turmeric and kimchi farming done here in this project to earn additional benefits besides energy revenue.

Despite the study's broad nature, it's vital to bring out several shortcomings in the analysis that could serve as a future research topic. Further, a detailed study can be undertaken to analyze the trend of output by evaluating the Performance ratio over the years. Because there is a threshold of 10% alternative energy penetration in the total system, the INPS power system is not prepared to handle the predicted growth in solar system penetration under current circumstances. To effective estimate the maximum permitted PV penetration in a network, a full techno-economic study should be undertaken for each particular network.

REFERENCES

Abdalla, S. N. M., and Ozcan, H., 2021, "Design and simulation of a 1-GWp solar photovoltaic power station in Sudan", *Clean Energy,* vol. 5(1), pp. 57–78.

Adhikari, R., 2020, "Utility scale solar power development in Nepal", *Bulletin of the Korea Photovoltaic Society,* vol. 6(1), pp 86–91.

Adhikary, A., 2020, "Utility scale grid-tied PV solar in Nepal: an unexplored avenue", *Research Gate.*

Alboaouh, K. A., and Mohagheghi, S., 2020, "Impact of Rooftop Photovoltaics on the Distribution System", *Journal of Renewable Energy,* vol. 2020, pp. 1–23.

Asano, H., Yajima, K., and Kaya, Y., 1996, "Influence of photovoltaic power generation on required capacity for load frequency control", *IEEE Transactions on Energy Conversion,* vol. 11(1), pp. 188–193.

Ayompe, L. M., Duffy, A., McCormack, S. J., and Conlon, M., 2011, "Measured performance of a 1.72kW rooftop grid connected photovoltaic system in Ireland", *Energy Conversion and Management,* vol. 52(2), pp. 816–825.

Bhusal, R., 2020, "Solar power project in Butwal starts commercial power generation", *My Republica,* Retrieved January 10, 2021, from https://myrepublica.nagariknetwork.com/news/solar-power-project-in-butwal-starts commercial-power-generation.

Bruen, M., Witnik, J., and Sthapit, B., 2017, "Surviving Three Natural Disasters: Lessons Learned at Upper Bhote Koshi in Nepal", *Hydro Review,* Retrieved November 21, 2021, from https://www.hydroreview.com/world-regions/surviving-three-natural-disasters-lessons-learned-at-upper-bhote-koshi-in-nepal.

Elamim, A., Hartiti, B., Haibaoui, A., Lfakir, A., and Thevenin, P., 2019, "Comparative study of photovoltaic solar systems connected to the grid: Performance evaluation and economic analysis", *Energy Procedia,* vol.159, pp. 333–339.

Elamim, Abderrazzak, Hartiti, B., Haibaoui, A., Lfakir, A., and Thevenin, P., 2018, "Performance evaluation and economical analysis of three photovoltaic systems installed in an institutional building in Errachidia, Morocco", *Energy Procedia*, vol. 147, pp. 121–129.

ElNozahy, M. S., and Salama, M. M. A., 2013, 'Technical impacts of grid-connected photovoltaic systems on electrical networks—A review", *Journal of Renewable and Sustainable Energy*, vol. 5(3).

Eltawil, M. A., and Zhao, Z., 2010, "Grid-connected photovoltaic power systems: Technical and potential problems—A review", *Renewable and Sustainable Energy Reviews,* vol. 14(1), pp. 112–129.

GoN., 2015, "Post Disaster Needs Assessment" Retrieved November 21, 2021, from https://www.npc.gov.np/images/category/PDNA_Volume_A.pdf.

GoN and NEA., 2018, "Universalizing Clean Energy in Nepal", Retrieved November 21, 2021from https://www.npc.gov.np/images/category/SUDIGGAA_final_version.pdf.

Ibrik, I. H., 2020, "Techno-economic assessment of on-grid solar PV system in Palestine" *Cogent Engineering*, vol. 7(1).

Magazine, N. S., 2020, "Middle Bhotekoshi Hydro Electricity Project Inundated, Causing Heavy Damage", *Spotlight Nepal,* Retrieved November 21, 2021, from https://www.spotlightnepal.com/2020/07/09/middle-bhotekoshi-hydro-electricity-project-inundated-causing-heavy-damage.

Manoj Kumar, N., Sudhakar, K., and Samykano, M., 2019, "Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia", *International Journal of Ambient Energy,* vol. 40(4), pp. 434–443.

Marion, B., Boyle, K., Hayden, H., Hammond, B., Fletcher, T., Canada, B., … Townsend, T., 2005, "Performance parameters for grid-connected PV systems", *IEEE Photovoltaic Specialists Conference 2005, Lake buena Vista, FL, USA: IEEE,* pp. 1601–1606.

Nurdiana, E., Subiyanto, I., Indarto, A., Riza, Wibisono, G., and Hudaya, C., 2020, "Performance analysis and evaluation of a 10.6 kWp grid-connected photovoltaic system in Serpong", *IOP Conference Series: Materials Science and Engineering*, vol. 909.

Pandey, I. M., 2015, *Financial management,* Tenth edition, Vikas Publishing House, India, ISBN 9325982293.

Park, C. S., 2012, *Fundamentals of Engineering Economics,* Third edition, Pearson Education, ISBN B0072VTG9G.

PVSYST., n.d, "Carbon Balance Tool", Retrieved March 1, 2022, from https://www.pvsyst.com/help/carbon_balance_tool.htm.

Sharma, V., and Chandel, S. S., 2013, "Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India", *Energy,* vol. 55, pp. 476–485.

Shiva Kumar, B., and Sudhakar, K., 2015, "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India", *Energy Reports,* vol. 1, pp. 184–192.

Skalik, L., and Skalikova, I., 2019, "Long-term Global Radiation Measurements in Denmark and Sweden" *IOP Conference Series: Materials Science and Engineering,* vol. 471, id. 102004.

SMA solar., n.d., "Performance ratio—Quality factor for the PV plant. SMA solar technology AG", Retrieved March 1, 2021, from https://files.sma.de/downloads/Perfratio-TI-en-11.pdf.

Thotakura, S., Chandan Kondamudi, S., Xavier, J. F., Quanjin, M., Reddy, G. R., Gangwar, P., and Davuluri, S. L., 2020, "Operational performance of megawatt-scale grid integrated rooftop solar PV system in tropical wet and dry climates of India", *Case Studies in Thermal Engineering,* vol. 18, id. 100602.

Tidball, R., Bluestein, J., Rodriguez, N., Knoke, S., International, I., and Macknick, J., 2010, "Cost and Performance Assumptions for Modeling Electricity Generation Technologies" *Renewable Energy,* vol. 211.

Tobnaghi, D. M., 2016, "A Review on Impacts of Grid-Connected PV System on Distribution Networks', *International Journal of Electrical and Computer Engineering,* vol. 10(1), pp. 137–152.

Chianese, D, et al., 2009, "Feasibility study on Grid connected PV system in Nepal", *Research Gate.*

Farhoodna. M, et al., 2013, "Power Quality Analysis of Grid-Connected Photovoltaic Systems in Distribution Networks", ISSN 0033-2097.

Eltawi A Mohamed, and Zhao. Zhengming., 2010, "Grid-connected photovoltaic power systems: Technical and potential problems", *Renewable and Sustainable Energy Reviews, Elsevier publication.*

Shrestha, Jagan Nath et al., 2014, "Impact of Small Decentralized PV Grid-Connected Plants on Load Shedding in Nepal", *IOE Graduate Conference,* pp. 27-35

Shrestha Ukesh, and Shrestha Jagan Nath., 2014, "A Techno-Economic Analysis of Utility Scale Photovoltaic Plant (A Case Study of 1 MWp Plant at Trishuli)", *IOE Graduate Conference,* pp.468-475

Shakya Ambish Kaji, and Shrestha Jagan Nath., 2015, "Case Study on Grid Integrated Solar PV for National Dasarath", *IOE Graduate Conference,* pp. 322-332.

Bajracharya Sajendra Man, and Maharjan Sanjeev., 2019, "Techno Economic Analysis of Grid Tied Solar System: A Case Study of Nepal Telecom, Sundhara, Kathmandu", *IOE Graduate Conference,* pp.211-218

Wiki-Solar., 2019, "Utility-scale solar in 2018 Still growing thanks to Australia and other later entrants", Retrieved 19 March 2020 from https://wiki-solar.org/library/public/190314_Utility-scale_solar_in_2018.pdf.

IEA, 2017, "Snapshot of Global Photovoltaic Markets" Retrieved 19 March 2020 from https://iea-pvps.org/wp-content/uploads/2020/01/IEA-PVPS__A_Snapshot_of_Global_PV_-_1992-2016__1_.pdf.

IRENA, 2019, "Renewable Power Generation Costs in 2018" Retrieved 19 March 2020 from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Renewable-Power-Generations-Costs-in-2018.pdf.

IS/IEC 61724, 1998, "Photovoltaic System Performance Monitoring - Guidelines for Measurement, Data exchange and Analysis" *ETD 28: Solar Photovoltaic Energy Systems*

GoN, 2006, “Rural Energy Policy”, *Government of Nepal, Ministry of Environment.*

IEA 2019, “Global Energy & CO2 Status Report 2019”, *IEA, Paris* Retrieved 19 March 2020 from https://www.iea.org/reports/global-energy-co2-status-report-2019.

Power Purchase Agreement, Nepal Electricity Authority – Ridi hydropower development company limited, September 25, 2018

Waaree, n.d., “WSM-330 4BB 40mm datasheet” Retrieved 19 March 2020 https://www.waaree.com/documents/WSM-330_4BB_40mm_datasheet.pdf.

Ridi hydro, 2022, “project 1”, Retrieved 19 March 2020 from https://ridihydro.com.np/project/1

Statista, 2021), “Nepal Inflation rate from 1986 to 2026”, Retrieved 20 March 2020 from https://www.statista.com/statistics/422594/inflation-rate-in-nepal.

Nepal Rastra Bank, 2018, “Banking & Financial Statistics”, Retrieved 20 March 2020 from https://www.nrb.org.np/contents/uploads/2020/11/Jestha-2075_Jun-2018.pdf.

Bank of Kathmandu, 2020, “Corporate Banking” Retrieved 20 March 2020 from https://www.bok.com.np/products/institutional-loans/corporate-banking.

Investment Board of Nepal, 2020, “FAQs”, Retrieved 20 March 2020 from https://ibn.gov.np/helpie_faq/what-are-the-corporate-income-tax-rates-in-nepal.

Electricity Regulatory Commission, 2020, “PPA and License Conditions Bylaws 2076”, Retrieved 20 March 2020 from http://erc.gov.np/storage/listies/April2020/ppa-and-license-conditions-bylaws-2076-final.pdf.

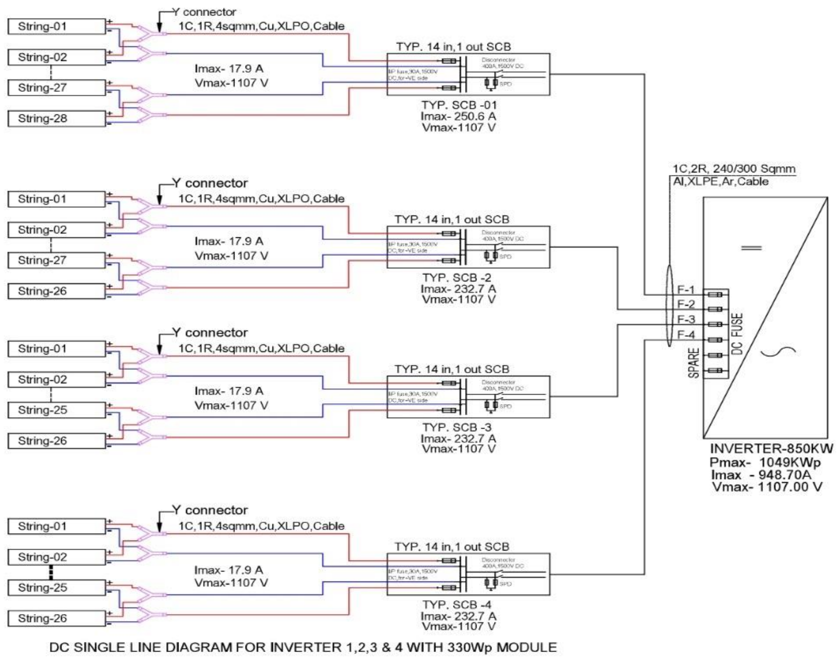
Mandal, Chandan Kumar., 2021, “Everything you need to know about Nepal’scarbon trade deal”, *The Kathmandu Post,* Retrieved March 24, 2022, from https://kathmandupost.com/climate-environment/2021/02/27/everything-you-need-to-know-about-nepal-s-carbon-trade-deal.

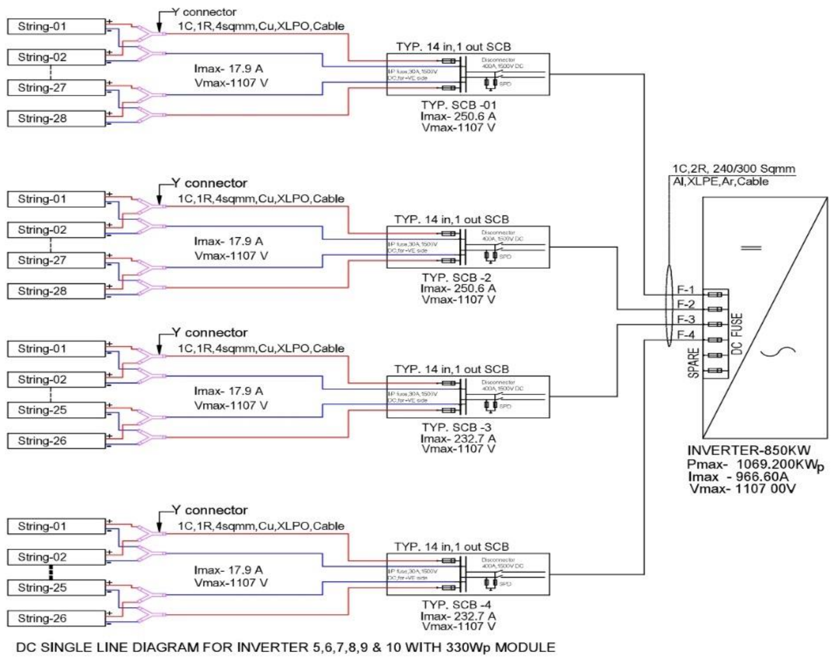
Appendix A: Financial analysis details

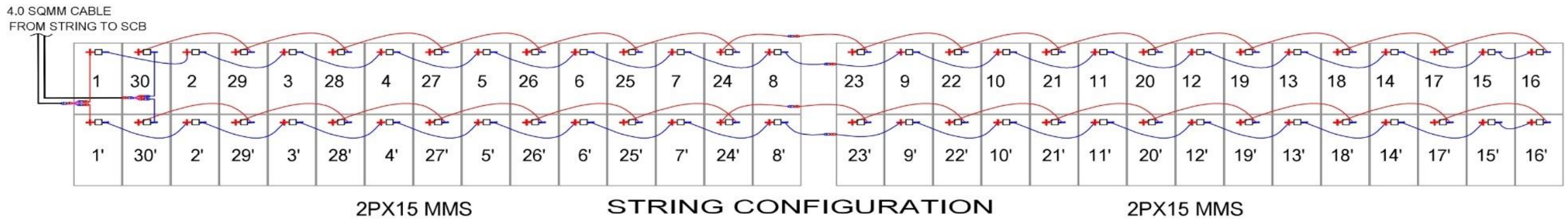
Year	O&M	Annual Energy	Tariff	Revenue	Gross Operation Profit	Interest Repayment	Principal Repayment	Total Debt Service Repayment	Net Cash flow to Equity	Net Cashflow Project	Cumulative Project Cashflow	DSCR
	(NPR million)	(KWh)	(NPR)	(NPR million)	(NPR million)	(NPR million)	(NPR million)	(NPR million)	(NPR million)	(NPR million)	(NPR million)	
0	Plant Base Cost of NPR 675 million (Debt:Equity = 70:30 %)								(202.50)	(675.00)	(675.00)	
1	4.70	14,510,583	7.30	105.93	101.23	56.61	17.20	73.81	27.42	101.23	(573.77)	1.37
2	4.94	14,394,498	7.30	105.08	100.14	50.99	20.13	71.12	29.03	100.14	(473.62)	1.41
3	5.19	14,278,414	7.30	104.23	99.05	44.70	23.55	68.25	30.79	99.05	(374.58)	1.45
4	5.45	14,162,329	7.30	103.39	97.93	37.67	27.55	65.22	32.72	97.93	(276.65)	1.50
5	5.73	14,046,244	7.30	102.54	96.81	29.78	32.23	62.02	34.79	96.81	(179.84)	1.56
6	6.02	13,930,160	7.30	101.69	95.67	20.95	37.71	58.67	37.00	95.67	(84.17)	1.63
7	6.33	13,814,075	7.30	100.84	94.51	11.07	44.13	55.19	39.32	94.51	10.35	1.71
8	6.65	13,697,990	7.30	100.00	93.34	-	-	-	93.34	93.34	103.69	-
9	6.99	13,581,906	7.30	99.15	92.16	-	-	-	92.16	92.16	195.85	-
10	7.35	13,465,821	7.30	98.30	90.95	-	-	-	90.95	90.95	286.80	-

Year	O&M	Annual Energy	Tariff	Revenue	Gross Operation Profit	Interest Repayment	Principal Repayment	Total Debt Service Repayment	Net Cash flow to Equity	Net Cashflow Project	Cumulative Project Cashflow	DSCR
11	7.72	13,349,736	7.30	97.45	89.73	-	-	-	89.73	89.73	376.53	-
12	8.12	13,233,652	7.30	96.61	88.49	-	-	-	88.49	88.49	465.02	-
13	8.53	13,117,567	7.30	95.76	87.23	-	-	-	87.23	87.23	552.25	-
14	8.96	13,001,482	7.30	94.91	85.95	-	-	-	85.95	85.95	638.19	-
15	9.42	12,885,398	7.30	94.06	84.64	-	-	-	84.64	84.64	722.84	-
16	9.90	12,769,313	7.30	93.22	83.31	-	-	-	83.31	83.31	806.15	-
17	10.41	12,653,228	7.30	92.37	81.96	-	-	-	81.96	81.96	888.11	-
18	10.94	12,537,144	7.30	91.52	80.58	-	-	-	80.58	80.58	968.69	-
19	11.50	12,421,059	7.30	90.67	79.18	-	-	-	79.18	79.18	1,047.87	-
20	12.08	12,304,974	7.30	89.83	77.74	-	-	-	77.74	77.74	1,125.61	-
21	12.70	12,188,890	7.30	88.98	76.28	-	-	-	76.28	76.28	1,201.89	-
22	13.35	12,072,805	7.30	88.13	74.78	-	-	-	74.78	74.78	1,276.68	-
23	14.03	11,956,720	7.30	87.28	73.26	-	-	-	73.26	73.26	1,349.93	-
24	14.74	11,840,636	7.30	86.44	71.69	-	-	-	71.69	71.69	1,421.63	-
25	15.49	11,724,551	7.30	85.59	70.09	-	-	-	70.09	70.09	1,491.72	-

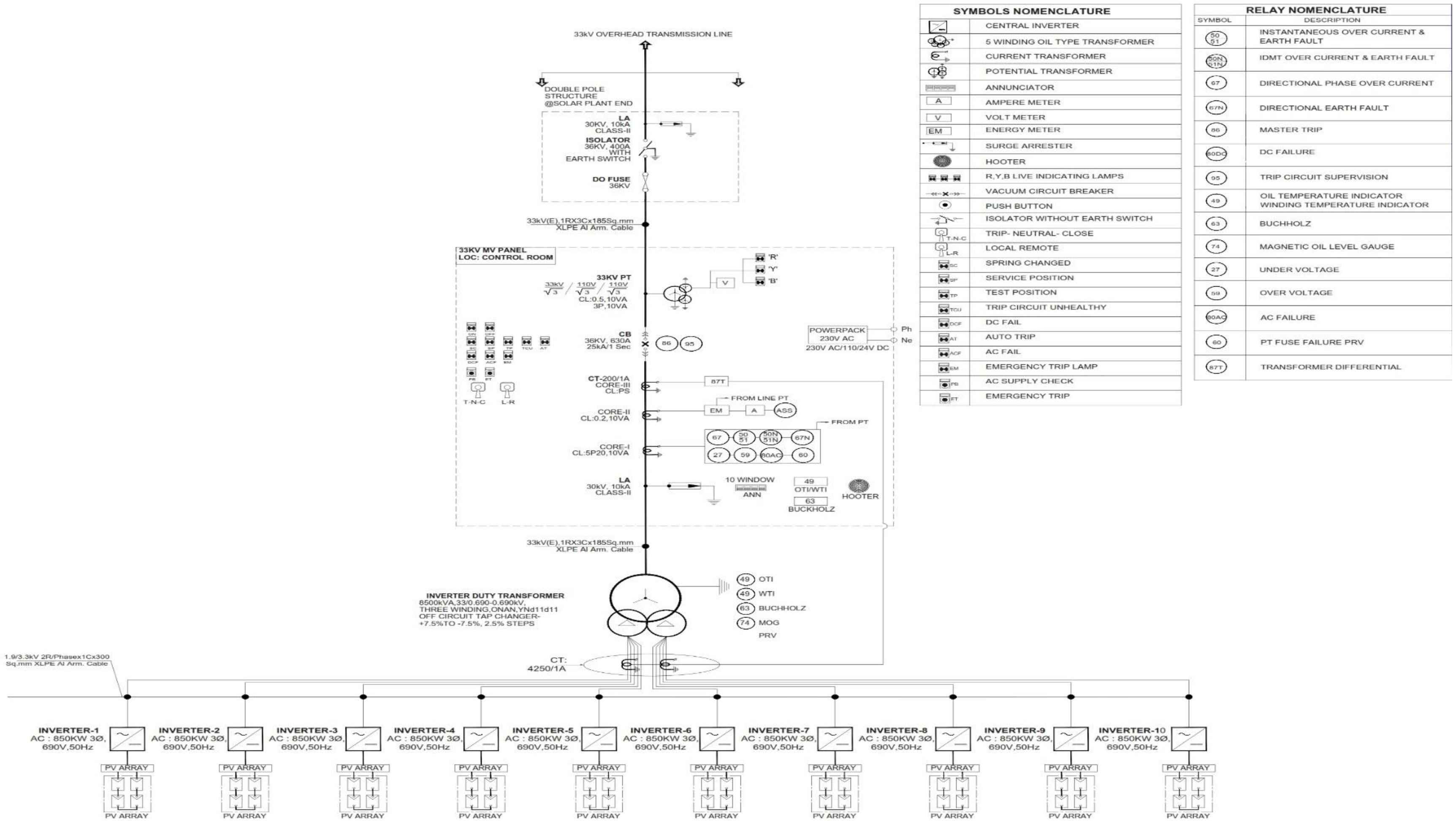
Appendix B: DC single line diagram







Appendix C: Plant detailed single line diagram



Appendix D: Originality Report

Performance Assessment of 8.5 MW Grid Connected Solar PV Plant in Butwal, Nepal

ORIGINALITY REPORT

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