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Performance Analysis of two same capacity Utility Scale Solar Plants in Nepal

by

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A THESIS

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

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The undersigned certify that they have read, and recommended to the Institute of Engineering for acceptance, a thesis entitled **"Performance Analysis of two Same capacity Utility Scale Solar Plants in Nepal"** submitted by Mr. Baibhav Kumar Thakur (078MSREE005) in partial fulfilment of the requirements for the degree of Masters of Science in Renewable Energy Engineering.

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ABSTRACT

The rapid growth in Utility Scale Solar Plants all around the world is acting like an Indicator of the rapid growth the Renewable Energy Sector has achieved in the last decade. Along with the number of benefits it has to offer, the growing Solar Power Generation sector comes along with several challenges. Despite the Design, Procurement, Installation and Commissioning of these Plants are much easier and convenient than the Hydropower Plants and the irradiance levels through-out the country is quite optimum for the Solar Power Generation, still there are many concerns and questions to the further growth of this Utility Scale Solar Power Generation Sector due to the factors, like: Power Generation hours limited to day, gradual degradation in efficiency of Solar Panels, requirement of huge land area, much variation in Power generation due to changing weather, shading, dust on panels etc. The current study conducts the Performance Analysis of two Utility Scale Solar Plants of Same Installed Capacity, 1.2096 MW in two different locations of the country to understand how Certain Parameters: Weather, Location, Design of the Plants, Wind Speed effect on the Power Generation from the Panels. 1.2096 MW each Solar Plants of Dhalkebar and Simara have been taken under the Study. The data of Power Generation for a period of 1 year (1st July, 2022 to 30th June, 2023) from these plants were collected to generate the idea of the actual Performance of each of these plants, which was further compared with the Outputs of Simulation done by using PVsyst 7.4.4. The annual S.Y., C.U.F. and P.R. of Dhalkebar and Simara Plants were found to be 1330,0.15,78% and 1207,0.138,72% respectively, while the values of the same obtained from results of Simulation were 1420,0.16,83.05% and 1351,0.154,81.55% respectively, which indicates the scope for further optimization of performance of these plants.

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, dusting off the Panels regularly is highlighted to maximize energy generation and export to the grid. Additional supplement research studies are also recommended.

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LIST OF ABBREVIATIONS

AC	Alternating Current
AEPC	Alternative Energy Promotion Centre
CUF	Capacity Utilization Factor
DC	Direct Current
DoED	Department of Electricity Development
GHI	Global Horizontal Irradiation
GTI	Global Tilted Irradiation
IEA	International Energy Agency
IPP	Independent Power Producers
mc-si	monocrystalline silicon
NEA	Nepal Electricity Authority
NLTC	No Load Tap Changer
NOCT	Normal Operating Cell Temperature
PR	Performance Ratio
PV	Photo Voltaic
PVGC	Photo Voltaic Grid Connected
PPA	Power Purchase Agreement
SCB	String Combiner Box
SLD	Single Line Diagram
STC	Standard Test Condition
VA	Volt Ampere
W	Watt
MW	Mega Watt
Wh	Watt hour
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
Wp	Watt Peak

Y_R	Reference Yield
Y_A	Array Yield
Y_F	Final Yield
S.Y.	Specific Yield

CHAPTER ONE: INTRODUCTION

1.1 Background

It's well known that the entire global community is currently focused on the "Switch Over from Fossil to Renewable" due to the climatic imbalance, pollution and degradation of planet's atmosphere caused by the continued use of Fossil Fuels for more than a century. Also, the non- replaceable nature of fossil fuels has made the concern for the development of Renewable Energy Harnessing Technologies, one of the major concerns of this century.

Nepal has abundant biomass, wind and solar resources, but the country is unable to efficiently utilize these resources because of the shortage of revolutionary technical skills and investment [1].

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. Diversification in Supply is another advantage. Relying only on hydropower is incredibly risky, especially as the consequences of climate change becomes more visible in the Himalayan region. Solar PV is a good supplement to hydropower, especially in the winter when the rivers are dry [2].

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. Water can accumulate in storage plants like Kulekhani and peaking run of river(PROR) projects like Kaligandaki A, Middle Marsyangdi, and Chilime can happen. The extra reserves can then be used to boost energy output during peak hours in the morning and evening [3].

Alike the Hydropower Energy Potential, it can be seen through the stats that Nepal is also blessed with the huge "Solar Energy Potential". The average GHI reaches up to 5.5 $kWh/m^2/day$ in northwest part of country while it is in the range of 4.4 to 4.9 $kWh/m^2/day$ in the southern part of the country [4].

The Presence of Plain Lands, Ease of access, Installment and Transportation in Terai region have attracted number of Investments in Solar Plants in Terai, as shown by Records of DOED. Here, in this Study, Author has presented the context of Generation of Solar Power from the two Same size Utility Scale Plants installed at two different locations in Madhesh Province, Terai, Nepal. It has been supposed in this research that no Utility Scale Plant is located in the Hilly and Himalayan Region.

1.2 Problem Statement

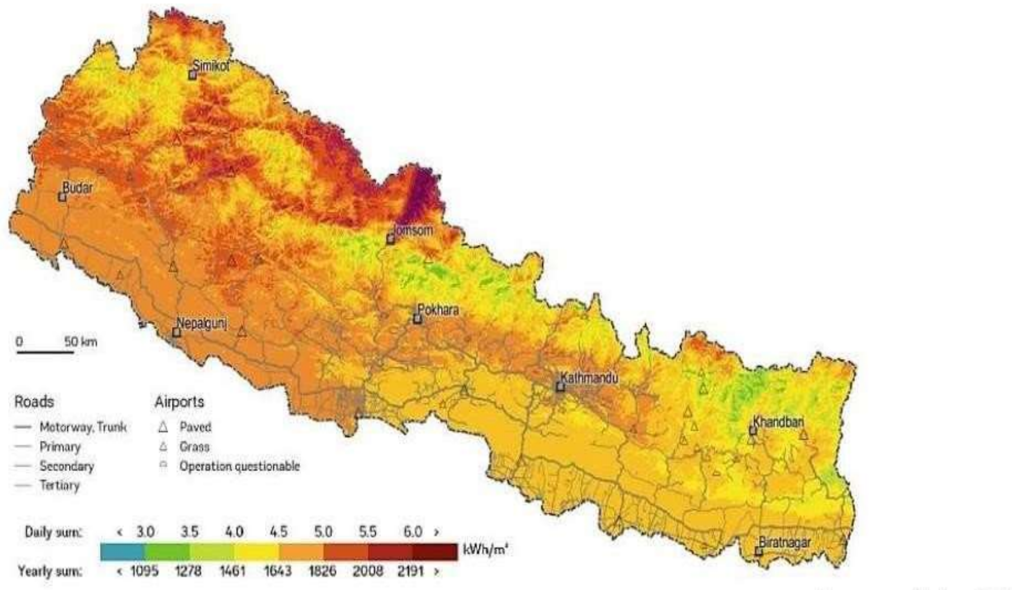
"Till now the main source of electrical energy in Nepal is Hydropower. Hydropower plants are more vulnerable to earthquake as it constitutes more than 60% of civil structures. Out of the 787 MW total installed capacity in the country, including off-grid, about 115 MW of hydropower generation facilities were badly damaged, while 60 MW were moderately damaged by the 2015 earthquake [5][6]. Similarly, a massive flood had badly damaged 45 MW, upper Bhotekoshi HPP in 2014 [7] and under construction 102 MW Middle Bhotekoshi in July 2020 [8].

Also due to climate change and global warming, water discharge in the river is decreasing every year. Thus, relying on a single source for electricity won't lead to energy security and reliability.

This thesis mainly aims at the performance analysis of ground mounted solar PV systems. So, the major scope of this thesis is the analysis of the existing solar system at Dhalkebar and Simara by simulating it on a computer program, to calculate performance and compare the results with actual performance, which is supposed to provide insights on the feasibility of Solar in local regions of Nepal.

1.3 Few Insights on the potential for solar plants' development in Nepal

As per Nepal Energy Sector Synopsis Report – 2022, The specific solar PV electricity output capacity of the country lies between 1400 kWh/kW_p and 1600 kWh/kW_p (= average daily total between 3.8 and 4.4 kWh/kW_p) [9].



(Nepal Energy Sector Synopsis Report – 2022,2022)

Figure 1.1: Global Horizontal Irradiation- a long-term average of daily and yearly total

Similarly, the maximum total solar radiation of about 777.27, 815.97, 914.03 and 704.51 W/m^2/day are observed in Kathmandu, Pokhara, Lukla and Biratnagar respectively with annual average solar energy measuring 5.19, 5.44, 4.61 and 4.95 kWh/m^2/day for respective places [10].

An article by Nepal economic forum in May, 2023 stated that the annual solar potential in Nepal is 50000 TWh [11].

1.4 Objectives of the study

The main objective of the study is to carryout performance analysis of two same capacity utility scale solar plants in Nepal.

The specific objectives are;

- To conduct performance analysis of 1.2096 MW Solar plants of Simara and Dhalkebar.
- To study details of existing systems and carry simulation using PVSYST
- To compare the actual performance data with simulated results of PVSYST

1.5 Limitations

- Only 2 Solar Plants have been taken under Study. Results could be more wholesome if more no. of Solar Plants would have been taken under Study.
- It has been Supposed that no Utility Scale Plants exist in Himalayan and Hilly Region.
- The actual weather Data of the Sites are unavailable, the data used has been imported from Meteonorm.

CHAPTER TWO: LITERATURE REVIEW

Research Papers related to the GII distribution on earth enriched the Understanding of the variation in Potential of Solar Energy Harnessing through-out the different locations in Nepal. Review of Papers related to variation of Solar Energy in different seasons played a detrimental role in deciding the regions having high Potential for Solar Plants in Nepal.

Nepal enjoys incredibly favorable weather conditions for the usage of photovoltaic power generation. When a two-axes sun tracker is added to a south-oriented 30° permanently inclined photovoltaic plant, its annual output increases to 2300 kWh/kWp [12].

Thapa et al. in 2022 reviewed papers on solar energy photovoltaic (PV) system potential and challenges in Nepal. The possibilities and difficulties of solar photovoltaic (PV) systems in Nepal are reviewed in this article. He submits the following conclusion [13],

- Solar PV cells need to become more efficient.
- To enhance the efficiency of solar modules and other components of photovoltaic systems, research in the field should be conducted.
- It is necessary to have bidirectional billing and metering systems connected in both urban and rural areas.
- Instead of rooftop and mini-scale solar PV systems, more unit-scale solar PV systems should be deployed.

Kafle et al. in 2022 have researched on the potential of rooftop photovoltaic system in Nepal. In Nepal, around 1.1 million solar-powered residential systems with a capacity of almost 30 MWp have been installed. To that aim, this study estimated the potential production from RPV in six Nepali cities (Kathmandu, Pokhara, Butwal, Nepalgunj, and Biratnagar) using a hierarchical geospatial technique based on open-source data. The potential theoretical production of RPV was discovered to vary between 637 GWh annually in Kathmandu and 50 GWh annually in Butwal. Furthermore, it was calculated that Nepal's urban homes have a total RPV potential of about 6.5 TWh annually [14].

A one MWp solar PV system at Trishuli was the subject of a techno-economic analysis by Shrestha et al. in 2014. The study revealed that the plant can produce 1768 MWh of energy annually, with a final yield of 4.81 kWh/kWp-day, a capacity utilization factor of 20.18 percent, and a performance ratio of 77.3 percent. These factors translate into an internal rate of return (IRR) of 12 percent over the plant's 25-year life. It comes to the conclusion that Nepal's utility-scale PVGC plant is a technically and economically feasible solution to the country's energy problems [15].

Mohd Rizwan et al. (2017) reviewed papers on solar energy derived from sunlight and talked about its potential future developments. They also attempted to go over how different kinds of solar panels operate, as well as highlight the different uses and strategies for promoting the advantages of solar energy. And the authors came to the conclusion that it is a more reliable alternative to meet the rising demand for energy and offers more advantages than other energy sources like fossil fuels and petroleum deposits. They concluded that research on solar cells and solar energy is promising and has a bright future globally [16].

Prashant et al. (2022) reviewed performance characteristics and efficiency enhancement techniques of solar PV system. Conducted a brief evaluation of various PV Performance Characteristics on various factors (such as varying irradiation, temperature, parallel & series connection, tilt angle, shading, environment impact, and different type of PV modules). This research revealed that the temperature, irradiation, shadow, and tilt angle of the PV modules have a significant impact on the system's performance and efficiency. The results that were concluded are [17],

- Higher efficiencies are always a benefit of solar radiation, but it also raises the temperature of the solar panel, which has a negative effect on it.
- It is best for solar panels to be between 15°C and 35°C in temperature. Between these ranges, panels are intended to operate at their most efficient levels. 25°C (77°F) is the ideal temperature to take into account. An increase of one degree in panel temperature would result in a 0.5% decrease in efficiency.
- Solar panel shading has a negative impact on PV module efficiency. If a single solar cell in the module is shaded, the power output will be zero. A 1% shade can cut power output by 50–70%.
- PV module and panel performance and efficiency, as well as the system's overall efficiency, are directly impacted by manufacturing and architectural processes.

Emily in 2019 anticipated that silicon solar cells will continue to become more affordable and widely used in the near future and said the following [18]:

- It is projected that by 2050, the amount of solar power produced in the US will have increased by at least 700% due to these cost reductions.
- Research on substitute designs for less costly and more effective solar cells will go on in the interim. In the future, silicon substitutes are probably going to show up on our rooftops and solar farms, contributing to the availability of clean, renewable energy sources.
- Increased solar cell production in large quantities and the development of new technologies that lower the cost and boost efficiency of the cells have made these advancements possible and will continue to do so.

A joint Study on Solar Energy conducted by Andrew Blakers and Sunil Prasad Lohani in Nepal in 2020 stated that the solar resource in Nepal is good enough for the production of electricity at a cost of NRs 4,800 (US$40) per MWh, once the solar industry becomes mature in Nepal, falling to below NRs 3,600 (US$30)/MWh in 2030. It concludes that the Best Sustainable Energy Sector in Nepal is Solar Sector [19].

CHAPTER THREE: METHODOLOGY

A research methodology is a comprehensive, conceptual assessment of the procedures used in a field of study. It's the framework based upon which the research progresses from Problem Identification to Conclusions.

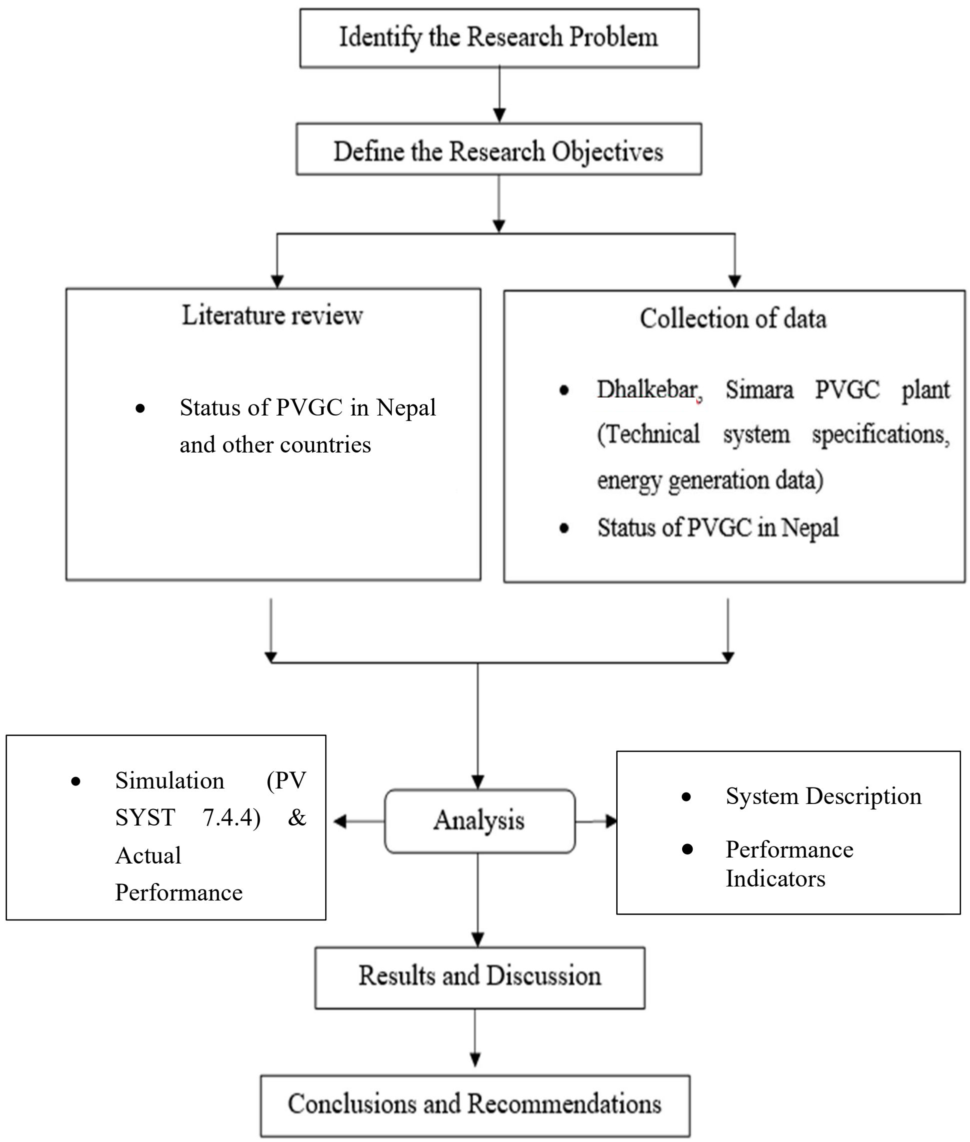


Figure 3.1: Research Methodology Diagram

The framework of research methodology adopted in this thesis work is as per figure 2 [20]. After problem formulation and initial literature review, data required were collected and system configuration was developed on PVSYST to estimate the technical outcome in MS excel. After a comparison of technical performance conclusion and recommendation is drawn.

3.1 Data Collection

Primary data is that which is collected by researchers themselves during their study 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.

During the data collection, the Installed System Description, Contract Energy Data and Actual Monthly generation Data for a period of 1 year from July 1st 2022 to June 30th 2023 was obtained from both the Plants by contacting Er. Prakash Kumar Karna from API Power. The System Description constituted of the data of Inverters used, Transformers, SCBs, Solar Modules. The sites were visited for the collection of the above data. Switch Yard and readings of Electrical Panels were observed periodically to see the variation in Generations.

The monthly generation data was obtained from the Plants' respective data bases of Power generation, collaborated by Er. Prakash Kumar Karna.

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 [21]. The International Energy Agency (IEA) Photovoltaic Power Systems Program has established parameters defining energy measures for PVGC systems, which are detailed in IEC standard 61724.

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.

Below are the Parameters based upon which the Performance Analysis was done for these two Plants.

3.2.1 Specific yield

The specific yield (SY) is the ratio of energy generated per KWp installed capacity of the system [21].

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

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 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 levelsand 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 [21].

$$CUF = \frac{Actual\ annual\ Energy\ from\ the\ Plant\ (KWh)}{Plant\ Capacity\ (KWp) * 24 * 365} \qquad \text{Equation 3.2}$$

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

3.2.3 Performance ratio

The Performance Ratio (PR) is used to assess the quality of an installation. It provides abaseline 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 PVpanels is lost due to system losses. The PR is calculated as follows,

$$Annual\ PR = \frac{Annual\ generation\ from\ plant}{Expected\ generation\ from\ plant} \qquad \text{Equation 3.3}$$

Also, the PR is the ratio of Y_F and Y_R [21]. 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.

$$PR = \frac{System\ Yield\ (YF)}{ReferenceYield(YR)} \qquad \text{Equation 3.4}$$

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/KWp [22].

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.

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.

$$L_c = Y_R - Y_A \qquad \text{Equation 3.5}$$

$$L_s = Y_A - Y_F \qquad \text{Equation 3.6}$$

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.

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.

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 [23].

3.3.1 Environmental factors

- The temperature of the PV module
- A PV module is especially efficient at lower temperatures.
- Solar irradiation and power dissipation
- When the sun is low in the sky in the morning, evening, and especially in winter,

thevalue for incident solar irradiation approaches that of power dissipation more closelythan at other times of day and year as a result, the PR value is lower than usual duringthese times.

- 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 %.
- 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 plantreduces as a result.

3.3.2 Other factors

- Measurement period
- If the measurement period is too short like less than one month, there are insufficientmeasurements 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.
- System efficiency
- The higher the efficiency of the PV modules, inverters, transformers and transmissionlines the higher the PR value.
- Use of different solar cell technologies in the PV modules and measuring gauge.
- If the PV plant's measuring gauge 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 inthe plant, variable solar irradiations can result in PV values of above 100%.

3.4 Reason to choose PVsyst as Simulation Tool

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

PVsystprogram 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 [23].

3.5 Simulation using PVSYST

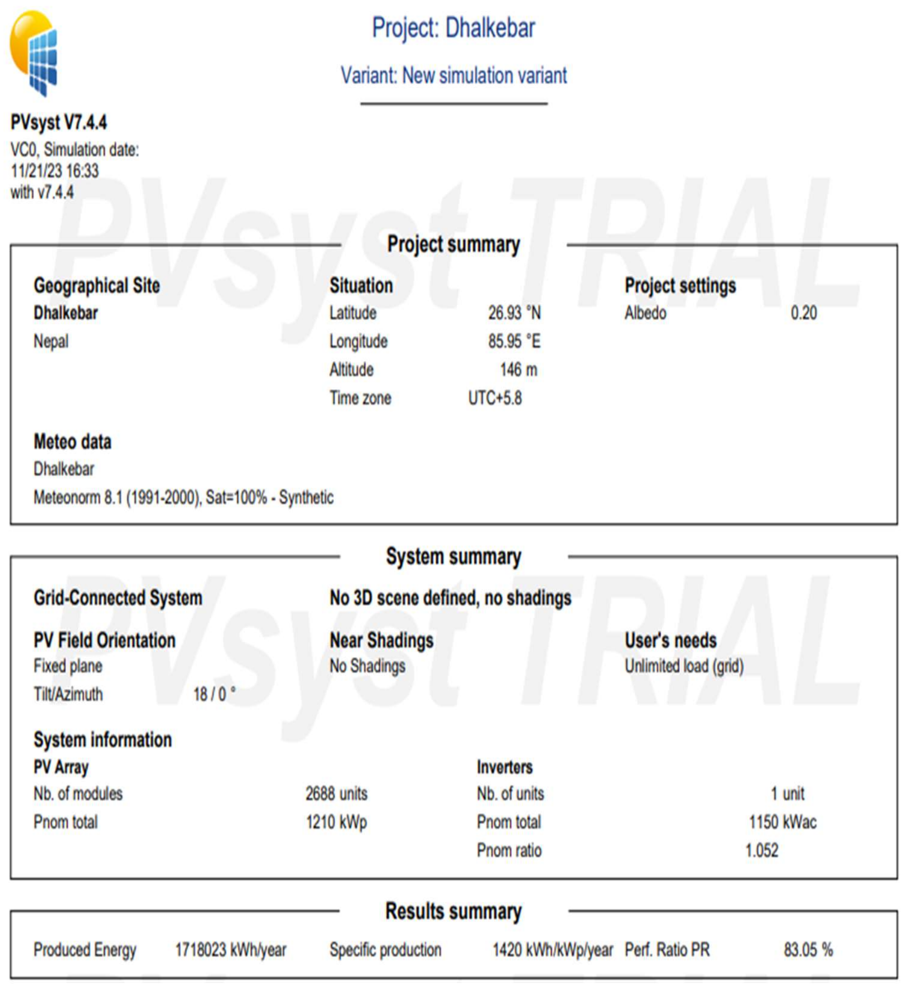
The system was designed in detail in PVSYST and thus simulated. In this software, the database regarding panels and inverters of different manufacturers is available. But the data of Inverter used in these plants was missing in the database of ABB Inverters. So, before defining the system, the Inverter data was imported in ABB's database and then the further simulation was done. Detailed modelling was done with this software to evaluate the performance capacity of solar PV Panels, which acted as a base for comparison from the actual performance of the plants.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 PVSYST simulation

Simulation was done for both the Plants using PV SYST 7.4.4 to generate the data of their Potential of Power Generation. Hence, to use the results for the comparative analysis with the actual generation obtained from these plants.

PVSYST simulation summary is shown in figure 4.1 and 4.2, below:



Project: Dhalkebar

Variant: New simulation variant

PVsyst V7.4.4
VC0, Simulation date:
11/21/23 16:33
with v7.4.4

Project summary

Geographical Site	Situation		Project settings	
Dhalkebar	Latitude	26.93 °N	Albedo	0.20
Nepal	Longitude	85.95 °E		
	Altitude	146 m		
	Time zone	UTC+5.8		

Meteo data
Dhalkebar
Meteonorm 8.1 (1991-2000), Sat=100% - Synthetic

System summary

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

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	18 / 0 °		

System information

PV Array		Inverters	
Nb. of modules	2688 units	Nb. of units	1 unit
Pnom total	1210 kWp	Pnom total	1150 kWac
		Pnom ratio	1.052

Results summary

Produced Energy	1718023 kWh/year	Specific production	1420 kWh/kWp/year	Perf. Ratio PR	83.05 %

Figure 4.1: Summary of Simulation for Dhalkebar Plant

Project: Simara

Variant: New simulation variant

PVsyst V7.4.4

VC0, Simulation date:
11/21/23 16:22
with v7.4.4

PVsyst TRIAL

Project summary

Geographical Site	Situation		Project settings	
Simara	Latitude	27.16 °N	Albedo	0.20
Nepal	Longitude	85.02 °E		
	Altitude	143 m		
	Time zone	UTC+5.8		

Meteo data
simara
Meteonorm 8.1 (1996-2015), Sat=100% - Synthetic

System summary

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

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	18 / 0 °		

System information

PV Array		Inverters	
Nb. of modules	2688 units	Nb. of units	1 unit
Pnom total	1210 kWp	Pnom total	1150 kWac
		Pnom ratio	1.052

Results summary

Produced Energy	1634502 kWh/year	Specific production	1351 kWh/kWp/year	Perf. Ratio PR	81.55 %

Figure 4.2: Summary of Simulation for Simara Plant

4.1.1 Major Results from Simulation

Following results were obtained from the Simulation, For Dhalkebar Plant, Annual Energy Produced, Specific Production/Yield and PR are 1420,0.162,83.05% respectively, whereas the same for Simara Plant are 1351,0.154,81.55% respectively. Despite, the average annual ambient temperature for both the Plants are almost same, 25.49 for Dhalkebar and 25. 20 for Simara Plant respectively, the (annual) irradiance is better for Dhalkebar Plant, hence the chances of generation are better. The energy Produced and Injected into Grid, both are higher for Dhalkebar Plant as compared to those of Simara Plant. The gap of Generation and Injection into Grid between both the

Plants are 2.9 % and 4.9 %, with Dhalkebar at the lead. The additional decline of 2 % in the Injection to Grid as compared to that of Dhalkebar Plant is due to the Grid Unavailability considered in case of Simara Plant, happening due to power outages.

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	101.2	51.04	14.67	125.5	119.4	134310	131411	0.866
February	111.8	59.94	19.57	129.3	123.2	135740	132771	0.849
March	156.8	74.76	25.36	171.7	163.7	175470	171644	0.826
April	148.2	86.89	29.91	151.3	143.8	152121	148964	0.814
May	163.6	95.91	31.56	159.9	152.0	160172	156798	0.811
June	145.3	94.96	31.13	139.4	132.2	140679	137596	0.816
July	139.0	87.61	29.87	133.8	126.7	135672	132709	0.820
August	147.7	90.15	29.80	147.2	139.6	149353	146192	0.821
September	129.6	66.82	28.81	137.0	130.2	138896	135769	0.819
October	130.2	67.83	26.84	146.4	139.5	149733	146495	0.827
November	113.3	56.09	21.61	138.2	131.7	144594	141525	0.846
December	103.1	50.84	16.47	130.6	124.3	139108	136150	0.862
Year	1589.8	882.84	25.49	1710.2	1626.4	1755847	1718023	0.830

Legends

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

Figure 4.3: Results of Simulation for Dhalkebar Plant

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	98.8	52.0	14.35	121.4	115.4	130079	123689	0.842
February	109.2	57.4	19.23	126.7	120.8	133188	113031	0.737
March	154.9	78.1	24.94	169.4	161.5	173563	169827	0.829
April	152.0	84.0	29.67	155.8	148.1	156522	153251	0.813
May	161.3	102.0	31.35	157.4	149.5	158093	154812	0.813
June	140.8	97.7	30.97	135.2	128.3	136655	133767	0.818
July	129.6	87.5	29.65	125.1	118.4	127082	124280	0.821
August	135.8	87.6	29.58	135.2	128.2	137401	122963	0.752
September	122.8	66.4	28.59	129.3	122.6	131074	128135	0.820
October	127.0	65.3	26.41	143.8	137.2	147436	144193	0.829
November	106.9	57.6	21.16	129.0	122.8	135279	132432	0.849
December	100.6	46.9	16.24	128.7	122.5	137085	134122	0.862
Year	1539.7	882.4	25.20	1657.0	1575.4	1703456	1634502	0.815

Legends

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

Figure 4.4: Results of Simulation for Simara Plant

4.1.2 Irradiance

The daily average estimated global tilted irradiance data for each month can be represented in figure 11. The variation of irradiance shows that it is highest in March-April and least in Jan, for both the Plants. The average annual irradiance is found to be 4.685 kWh/m^2/day and 4.54 kWh/m^2/day for Dhalkebar and Simara Plants respectively. The figure below shows the similar trend of variation in irradiance throughout the year for both Dhalkebar and Simara Plants which indicates that the irradiance is almost similar across the specific region having similar climate and temperature. 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 tobe unique for each day of the year.

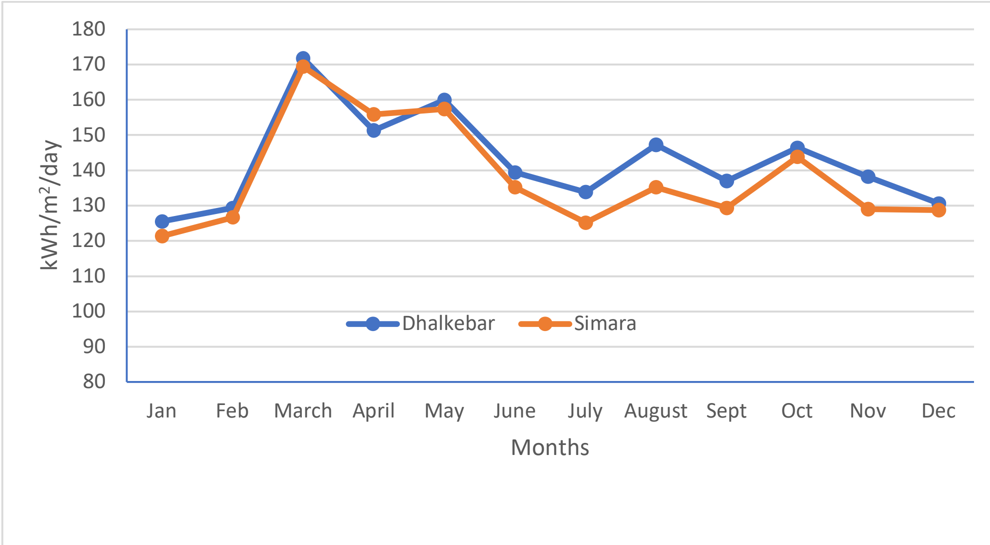


Figure 4.5: Irradiance Fluctuation through out the Year

4.1.3 Performance Variation

The estimated monthly parameters of Performance are shown in the tables below:

Table 4.1: Monthly Performance Parameter Table of Dhalkebar Plant

Months	Tamb (°C)	GlobInc (kWh/m²)	E_Grid (KWh)	specific energy yield (kWh/kWp)	PR (%)	CUF (%)
January	14.67	125.5	131411	108.64	87	15.1
February	19.57	129.3	132771	109.76	85	15.2
March	25.36	171.7	171644	141.9	83	19.7
April	29.91	151.3	148964	123.15	81	17.1
May	31.56	159.9	156798	129.6	81	18.0
June	31.13	139.4	137596	113.8	81	15.8
July	29.87	133.8	132709	109.7	82	15.2
August	29.8	147.2	146192	120.86	82	16.8
September	28.81	137	135769	112.24	82	15.6
October	26.84	146.4	146495	128.34	83	17.8
November	21.61	138.2	141525	117	85	16.3
December	16.47	130.6	136150	112.56	86	15.6
Annual	**25.5**	**1710.3**	**1718024**	**1427.55**	**83**	**16.52**

Data from Table 9 show that specific yield varies from 108.64 (January) to 141.9 (March) with an yearly average of 1427.55 KWh/KWp. Similarly, the performance ratio varies from 87% (January) to 81% (April, May, June). The yearly average capacity utilization factor is 16.52 %. It varies from 15.1 % to 19.7 %.

The above data present the combined consequence of irradiance and temperature on the energy output of the system. Even if the irradiance is good, the energy output decreases up to some range as a result of rising temperature.

Table 4.2: Monthly peformance parameters of Simara Plant

Months	Tamb (°C)	Glob. Inc (kWh/m²)	E_Grid (KWh)	specific energy yield (kWh/kWp)	PR (%)	CUF (%)
January	14.35	121.4	123689	102.3	84	14.2
February	19.23	126.7	113031	93.4	74	13.0
March	24.94	169.4	169827	140.4	83	19.5
April	29.67	155.8	153251	126.7	81	17.6
May	31.35	157.4	154812	128.0	81	17.8
June	30.97	135.2	133767	110.6	82	15.4
July	29.65	125.1	124280	102.7	82	14.3
August	29.58	135.2	122963	101.7	75	14.1
September	28.59	129.3	128135	105.9	82	14.7
October	26.41	143.8	144193	119.2	83	16.6
November	21.16	129	132432	109.5	85	15.2
December	16.24	128.7	134122	110.9	86	15.4
Annual	**25.2**	**1657**	**1634502**	**1351.3**	**82**	**15.6**

Similarly, Table 10 shows that specific yield varies from 93.4 (January) to 140.4 (March) withayearly average of 1351.3 kWh/kWp. Similarly, the performance ratio varies from 86% (January) to 74% (February). The yearly average capacity utilization factor is 15.6 %. It varies from 13 % to 17.8 %.

Also the data above help to understand the combined consequence of irradiance and temperature 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.

4.1.4 Estimated generation in plant lifetime

Sankey diagram is 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 13 and 14 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 modulestructures. This gives the insight to reduce avoidable losses. For example, by regularly dusting off the Panels, the 3 % loss in total generation due to soiling can be minimized in both the Plants.

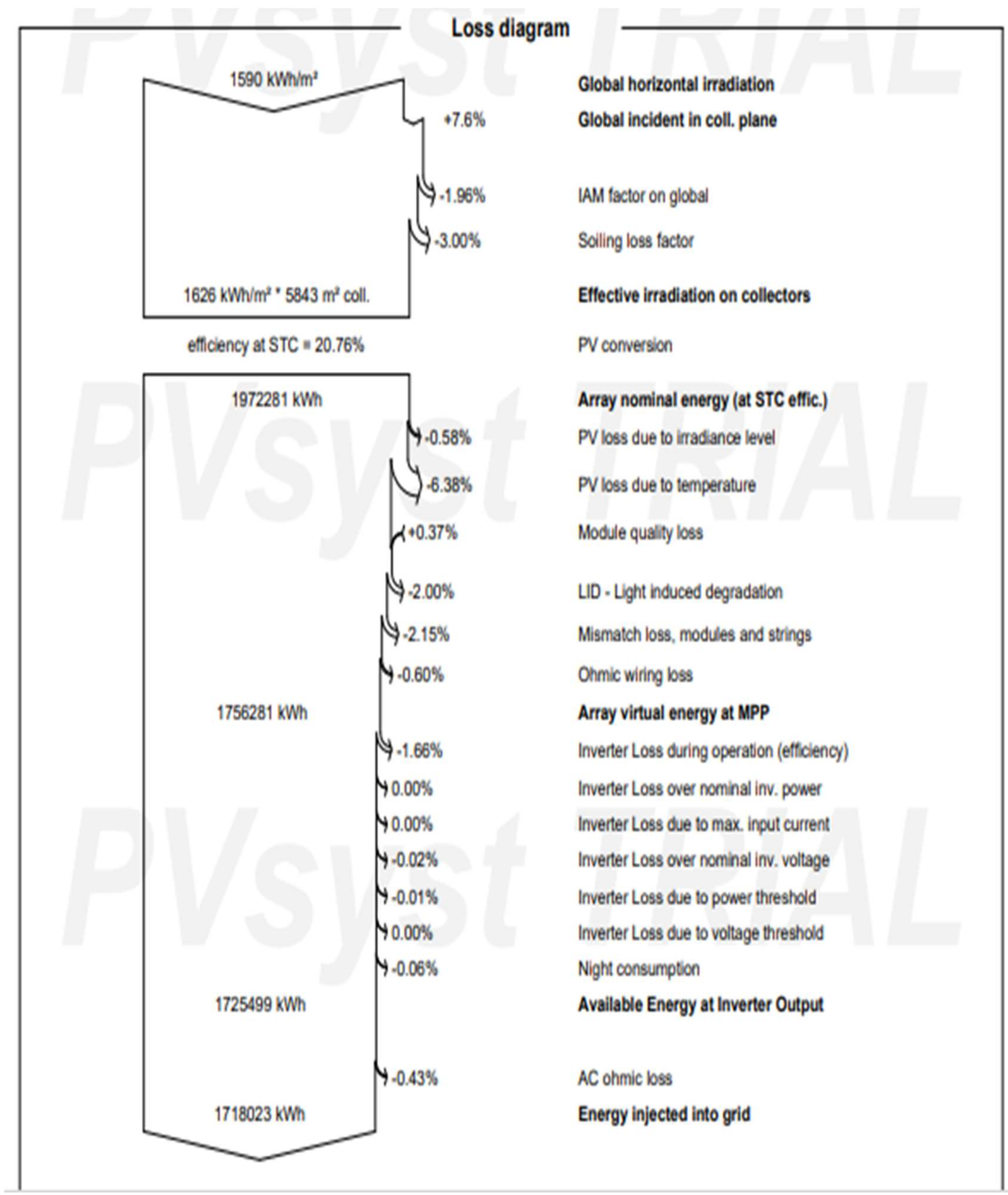


Figure 4.6: Simulated Loss Diagram for Dhalkebar Plant

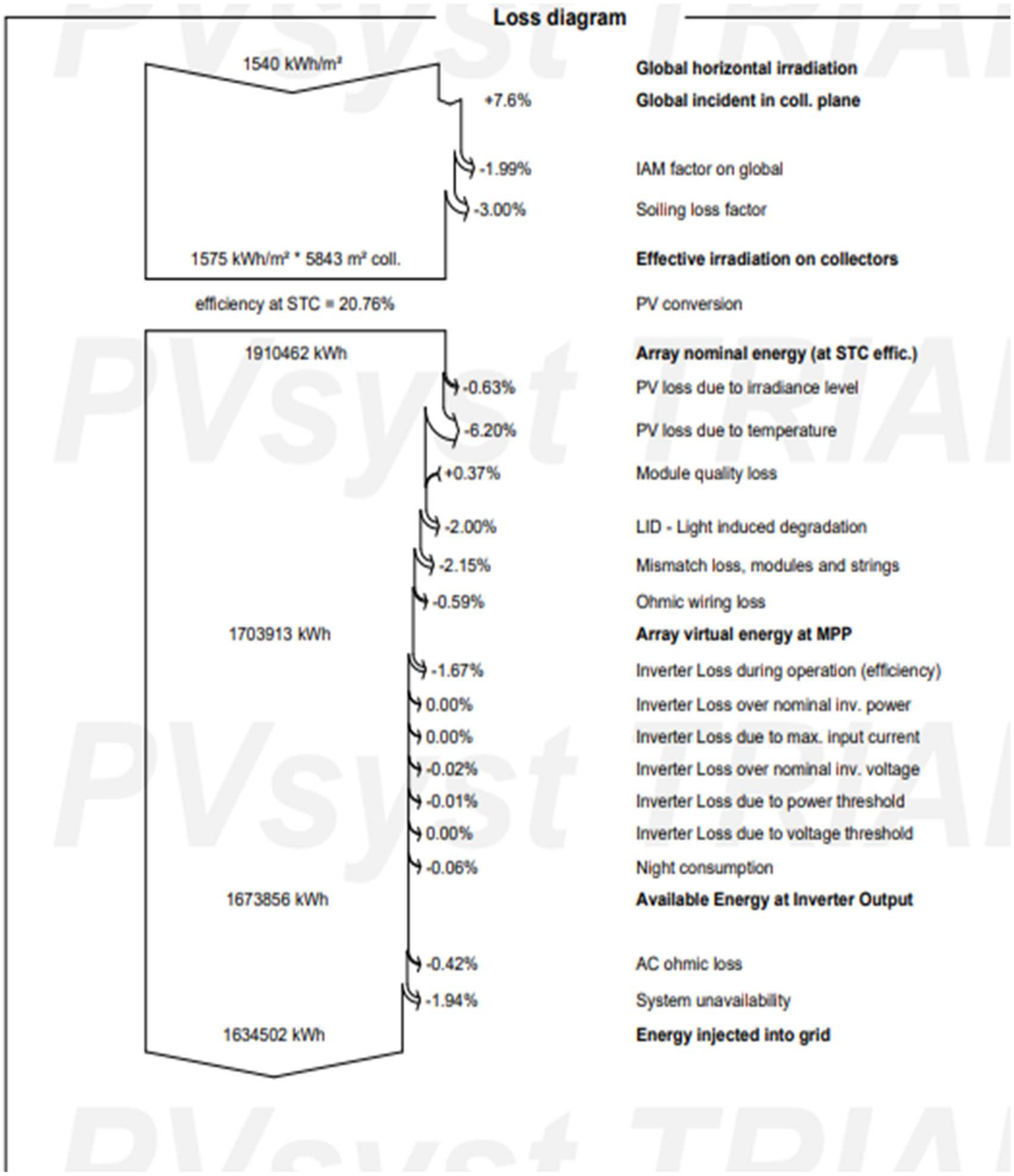


Figure 4.7: Simulated Loss Diagram for Simara Plant

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 11, Annually for Dhalkebar Plant, energy input of GTI 1711 kWh/m^2 produces specific energy output of 1420.4 kWh/kWp considering soiling, reflectivity, spectral correction and all other associated losses. With consideration of conversion loss from solar radiation to electrical energy and technical availability of grid,the energy output becomes 1718 MWh.

Similarly, annually for Simara Plant, energy input of GTI 1657 kWh/m^2 produces specific energy output of 1351.2 kWh/kWp considering soiling, reflectivity, spectral correction and all other associated losses. With consideration ofconversion loss from solar radiation to electrical energy and technical availability of grid,the energy output becomes 1634.5 MWh.

Table 4.3: Energy Balance Table for Dhalkebar Plant (Simulated)

Energy Conversion step	**Input Energy Kwh/m²**	**Energy gain/ loss Kwh/m²**	**Energy output KWh**	**Energy yield Kwh/kwp**	**Energy loss/gain %**
Theoretical GHI	1590	-			-
Loss due to horizon shading	1590	0			0
Particular site GHI	1590	0			0
Effective to surface of PV modules	1711	136			7.6
GTI	1711				
Dust, dirt and soiling	1660	-51			-3
Loss due to IAM factor	1627	-33			-1.96
Effective irradiation on modules	1627	-84			-4.96
Nominal array energy (at STC in 62403 m²)	1627		1972281	1630.5	-20.76
Effect of irradiance level in PV			1960842	1621.1	-0.58
Effect of temperature in PV			1835740	1517.6	-6.38

Effect of module quality			1842532	1523.3	0.37
Effect of Light Induced Degr.			1805681	1492.8	-2
Modules, strings mismatch loss			1766869	1460.7	-2.15
Effect of wire resistance			1756268	1451.9	-0.6
Array Virtual energy at MPP			1756268	1451.9	-11.34
Effect of inverter operation			1727114	1427.8	-1.66
Voltage loss			1726759	1427.5	-0.02
Effect of Inverter Power threshold			1726586	1427.4	-0.01
Effect of Night Consumption			1725550	1426.5	-0.06
Available Energy at Inverter			1725550	1426.5	-1.75
Effect of Ac ohmic losses			1718130	1420.4	-0.43

Table 4.4: Energy Balance Table for Simara Plant(Simulated)

Energy Conversion step	**Input Energy Kwh/m²**	**Energy gain/ loss Kwh/m²**	**Energy output KWh**	**Energy yield Kwh/kwp**	**Energy loss/gain %**
Theoretical GHI	1540	-			-
Loss due to horizon shading	1540	0			0
Particular site GHI	1540	0			0

Effective to surface of PV modules	1657	136			7.6
GTI	1657				
Dust, dirt and soiling	1607	-50			-3
Loss due to IAM factor	1575	-32			-1.99
Effective irradiation on modules	1575	-82			-4.96
Nominal array energy (at STC in 62403 m²)	1575		1910462	1579.4	-20.76
Effect of irradiance level in PV			1898426	1569.5	-0.63
Effect of temperature in PV			1780724	1472.2	-6.2
Effect of module quality			1787313	1477.6	0.37
Effect of Light Induced Degr.			1751567	1448.1	-2
Modules, strings mismatch loss			1713908	1416.9	-2.15
Effect of wire resistance			1703796	1408.6	-0.59
Array Virtual energy at MPP			1703796	1408.6	-11.2
Effect of inverer operation			1675343	1385	-1.67
Voltage loss			1675008	1384.8	-0.02
Effect of Inverter Power threshold			1674840	1384.6	-0.01
Effect of Night Consumption			1673835	1383.8	-0.06
Available Energy at Inverter			1673835	1383.8	-1.76

Effect of Ac ohmic losses			1666805	1378	-0.42
Effect of Grid Unavailability			1634469	1351.2	-1.94

Since the plant module warranty period and PPA both were valid for 25 years so it can be assumed that the useful life of both these solar PV is 25 years. As shown in table 4.3 the plant degrades by 13.75 % in 25 years of operation. This degradation mainly considers solar panel ageing loss of 0.55% per year for upto 25 years. From the Simulation results, The Dhalkebar plant's and Simara Plant's average annual yields are 1,323.18 kWh\kWp and 1258.75 respectively, whereas the lifetime generation and average annual generation for both the plants are 41731.181 MWh and1669.25 MWh, and 39699.16 3 MWh and 1587.97 MWh respectively.

Table 4.5: Lifetime Generation by Dhalkebar Plant

Year	Degradation rate	Final yield	E_grid
	%	kWh/kWp	kWh
Simulated	-	1,420.40	1,718,130.00
1	0.55	1,412.60	1,708,680.29
2	0.55	1,404.83	1,699,282.54
3	0.55	1,397.10	1,689,936.49
4	0.55	1,389.42	1,680,641.84
5	0.55	1,381.78	1,671,398.31
6	0.55	1,374.18	1,662,205.62
7	0.55	1,366.62	1,653,063.49
8	0.55	1,359.10	1,643,971.64
9	0.55	1,351.63	1,634,929.79
10	0.55	1,344.19	1,625,937.68
11	0.55	1,336.80	1,616,995.02
12	0.55	1,329.45	1,608,101.55
13	0.55	1,322.14	1,599,256.99
14	0.55	1,314.87	1,590,461.08
15	0.55	1,307.63	1,581,713.54
16	0.55	1,300.44	1,573,014.12
17	0.55	1,293.29	1,564,362.54
18	0.55	1,286.18	1,555,758.55
19	0.55	1,279.10	1,547,201.87
20	0.55	1,272.07	1,538,692.26
21	0.55	1,265.07	1,530,229.46
22	0.55	1,258.11	1,521,813.19
23	0.55	1,251.19	1,513,443.22
24	0.55	1,244.31	1,505,119.28
25	0.55	1,237.47	1,496,841.13
Average	**0.55**	**1,323.18**	**1,669,247.26**
Commulative	**13.75**		**41,731,181.49**

Table 4.6: Lifetime Generation by Simara Plant

Year	Degradation rate	Final yield	E_grid
	%	kwh/kwp	Kwh
Simulated	-	1,351.20	1,634,469.00
1	0.55	1,343.82	1,625,479.42
2	0.55	1,336.42	1,616,539.28
3	0.55	1,329.07	1,607,648.32
4	0.55	1,321.76	1,598,806.25
5	0.55	1,314.49	1,590,012.82
6	0.55	1,307.27	1,581,267.75
7	0.55	1,300.08	1,572,570.77
8	0.55	1,292.92	1,563,921.64
9	0.55	1,285.81	1,555,320.07
10	0.55	1,278.74	1,546,765.81
11	0.55	1,271.71	1,538,258.59
12	0.55	1,264.71	1,529,798.17
13	0.55	1,257.76	1,521,384.28
14	0.55	1,250.84	1,513,016.67
15	0.55	1,243.96	1,504,695.08
16	0.55	1,237.12	1,496,419.25
17	0.55	1,230.31	1,488,188.95
18	0.55	1,223.55	1,480,003.91
19	0.55	1,216.82	1,471,863.89
20	0.55	1,210.13	1,463,768.64
21	0.55	1,203.47	1,455,717.91
22	0.55	1,196.85	1,447,711.46
23	0.55	1,190.27	1,439,749.05
24	0.55	1,183.72	1,431,830.43
25	0.55	1,177.21	1,423,955.36
Average	**0.55**	**1,258.75**	**1,587,966.51**
Commulative	**13.75**		**39,699,162.74**

4.2 Actual energy generation and performance indicators

The Simara Plant had started its generation from 9th July, 2022, whereas Dhalkebar Plant had started its generation just 6 months prior to it. The performance indicator table 15 and 16 are developed, which show that both the plants are generating less than that of simulated and contract energy, annually. The average annual PR,CUF, Specific energy are found to be 0.78, 15.2 % and 1710 kWh/kWp, and 0.72, 13.8%, 1657 kWh/kWp respectively for Dhalkebar and Simara Plants respectively. The annual contract energy for Dhalkebar and Simara Plant from July, 2022 to 16 June 2023 is 1701930.151 KWh and 1612528.24 KWh respectively. The Simulated value of annually Energy Generation for Dhalkebar and Simara Plant are 1718024 KWh and 1634502 KWh respectively, which are very close to the Values of Contract Energy of both the Plants. Some differences as seen maybe due to different metrological data sources and loss calculations under study. With a difference of 0.9% and 1.34 % in a year value, the results of estimated energy to the grid (Egrid) using PVsyst software are quite near to the contract energy, for Dhalkebar and Simara Plants respectively. For Dhalkebar Plant, the actual generation for the first year of operation is found to be 6.3 % and 5.45 % less than those of estimated and contract values respectively, whereas for Simara Plant, the same is found to be 10.67 % and 9.46 % less than those of estimatedand contract values respectively. It can be seen that the generation is higher than the simulated value in the months of April, June, July, August and October at Dhalkebar Plant and the same in the months of May, June and August at Simara Plant.

Table 4.7: Actual Generation by Dhalkebar Plant

		GlobInc kWh/m²	Simulated Energy MWh	Actual Energy Exported to the Grid	Final Yield kWh/kW_p	PR	CUF
Month	**Days**					**%**	**%**
January	31	125.5	131411	84736	70.1	56	9.4
February	28	129.3	132771	110798	91.6	71	13.6
March	31	171.7	171644	145794	120.5	70	16.2
April	30	151.3	148964	156682	129.5	86	18
May	31	159.9	156798	144325	119.3	75	16
June	30	139.4	137596	148820	123	88	17.1
July	31	133.8	132709	149417	123.5	92	16.6
August	31	147.2	146192	151507	125.3	85	16.8
September	30	137	135769	105558	87.3	64	12.1
October	31	146.4	146495	157058	129.8	89	17.5
November	30	138.2	141525	133567	110.4	80	15.3
December	31	130.6	136150	120851	99.9	77	13.4
Annual		**1,710**	**1718024**	**1609113**	**1330.3**	**78**	**15.2**

Table 4.8: Actual Generation by Simara Plant

Month	Days	Glob. Inc kWh/m²	Simulated Energy MWh	Actual Energy Exported to the Grid	Final Yield kWh/kWp	PR %	CUF %
January	31	121.4	123689	68506	56.6	47	7.6
February	28	126.7	113031	87715	72.5	57	10.8
March	31	169.4	169827	137621	113.8	67	15.3
April	30	155.8	153251	146555	121.2	78	16.8
May	31	157.4	154812	165746	137	87	18.4
June	30	135.2	133767	146159	120.8	89	16.8
July	31	125.1	124280	88910	73.5	59	9.9
August	31	135.2	122963	150077	124.1	92	16.7
September	30	129.3	128135	120060	99.3	77	13.8
October	31	143.8	144193	138054	114.1	79	15.3
November	30	129	132432	113645	94	73	13
December	31	128.7	134122	96953	80.2	62	10.8
Annual		**1,657**	**1634502**	**1460001**	**1207**	**72**	**13.8**

4.3 Performance Comparison

From the literature, a few recent studies on similar grid-connected PV systems have been included for comparison. Table 17 shows the comparison with current literature based on measures such as performance factor, specific energy factor, and capacity utilization 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 PVsystems.

Table 4.9: Performance Comparison Table

Location	Installed DC Capacity	PV	Monitor Duration	CUF	PR	References
	KW$_p$			%	%	
Dhalkebar, Nepal	1209.6	mc-si	July 2022- Sep-21	15.2	78	This study
Simara, Nepal	1209.6	mc-si	July 2022- Sep-21	13.8	72	This study
Andra Pradesh, India	10000	pc-si	Oct 2018-2019	20.8	88	Thotakura et al., 2020
Ramagundam, India	1000	pc-si	Apr 2014-Narch 2015	17.68	76.2	Kumar & Sudhakar, 2015
Khatkar-Kalan, India	190	pc-si	2011	9.27	74	Sharma & Chandel, 2013
Dublin, Ireland	1.72	mc-si	Nov 2008- Oct 2009	10.1	81.5	Ayompe et al., 2011

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study provides a first-year operation performance including the estimated technical outcome of 1.2096MW grid connected solar PV Plants in Dhalkebar and Simara, Nepal.

The PVSYST simulated, PPA contract and actual monthly energy exported to the grid is found to be following a similar trend for both the Plants, where Simulated Energy is greater than the Contract Energy, and Contract Energy is greater than Actual Energy Injected Intpo Grid.

As far as actual energy injected into the grid is compared to PVSYST results, the Dhalkebar Plant is closer to the expected generation with the discrepancy of 6.3 % whereas the same for Simara Plant is 10.7 %. The generation in both the Plants is low in winter, maximum in autumn, and average in the Summer, which clarifies that the foggy weather in winter sheds off the irradiance and elevated ambient temperature in summer increases the temperature of cells much above 25 deg. Celcius, causing in decline the generation in these two seasons. Grid unavailability is also adding to system loss in case of Simara Plant as the injection of energy has been made to public feeder which often goes down.

Dhalkebar Plant is more efficient than the Simara Plant despite having each and every component starting from modules to the transformer same as that in Simara Plant. Despite the difference between annual average ambient atmospheric temperature of these 2 locations is negligible, 1.17%, there is certain gap of 3% between the average annual irradiance between them, Dhalkebar has comparatively good radiance, making it efficient by 9%, generation wise. Also, the plant could have attained high performance if it had utilized a more efficient monocrystalline PV module having an efficiency of about 22% and 23% respectively for both Dhalkebar and Simara Plants.

5.2 Recommendations

The analysis could have been more precise to the actual results if the actual/measured irradiance data was available, which can be measured by pyranometer for prolonged certain period of time, as an improvement to the current work. The irradiance data used was imported from Meteonorm from within PVsyst, as the actual data were not available.

Analysis based on Daily Generation should be done to yield more accurate Performance instead of Monthly Generation.

Although the manual cleaning of the PV array is done on certain intervals of days, as the plants lie in the developing city of Nepal, the dust accumulation takes place within a day. As a result, the cleaning of panels' surface more frequently is advised. During day time 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 rate of degradation and check the efficiency of it against the rated value.

Despite the study's broad nature, there's several shortcomings in the analysis that could serve as a future research topic. Further, a detailed study be undertaken to analyze the trend of output by evaluating the Performance ratio over the years. As 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 effectively estimate the maximum permitted PV penetration in a network, a full techno-economic study should be undertaken for each particular network.

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ANNEXES

Annex A : Salient Features of the Plants

Dhalkebar 1.2096 MW Utility Solar Plant	
1. Project Location	
Province	Madhesh
District	Mithila
Municipality/ward	
Geographical Coordinate	
Latitude	26°55'12" to 26°55'38" N
Longitude	85°56'38" to 85°56'56" E
2. General	
Installed Capacity	1209.6 kW_p [DC]
Contract Annual Energy	17,03,382 KWh
Transformer	1250 KVA (11/0.69 KV)
Transmission line	11 kV

Simara 1.2096 MW Utility Solar Plant	
1. Project Location	
Province	Madhesh
District	Bara
Municipality/ward	
Geographical Coordinate	

Latitude	27°08’47” to 27°09’18” N
Longitude	85°00’28” to 85°01’04” E
2. General	
Installed Capacity	1209.6 kW_p [DC]
Contract Annual Energy	16,33,933 KWh
Transformer	1250 KVA (11/0.69 KV)
Transmission line	11 kV

Annex B: SLD of the Plants

The overall plant’s single line diagram (SLD) is shown in fig 10 for both Dhalkebar and Simara Plant, as the Plants are identical. At each Plants, there is 1 central inverter of 1MW AC Capacity fed from the 4 SCB, each SCB is connected to 672 modules arranged in 24 parallel strings, with each string having 28 modules in series. Various protective control relay, switchgear is used to protect the transformer and to ensure proper quality power supply.

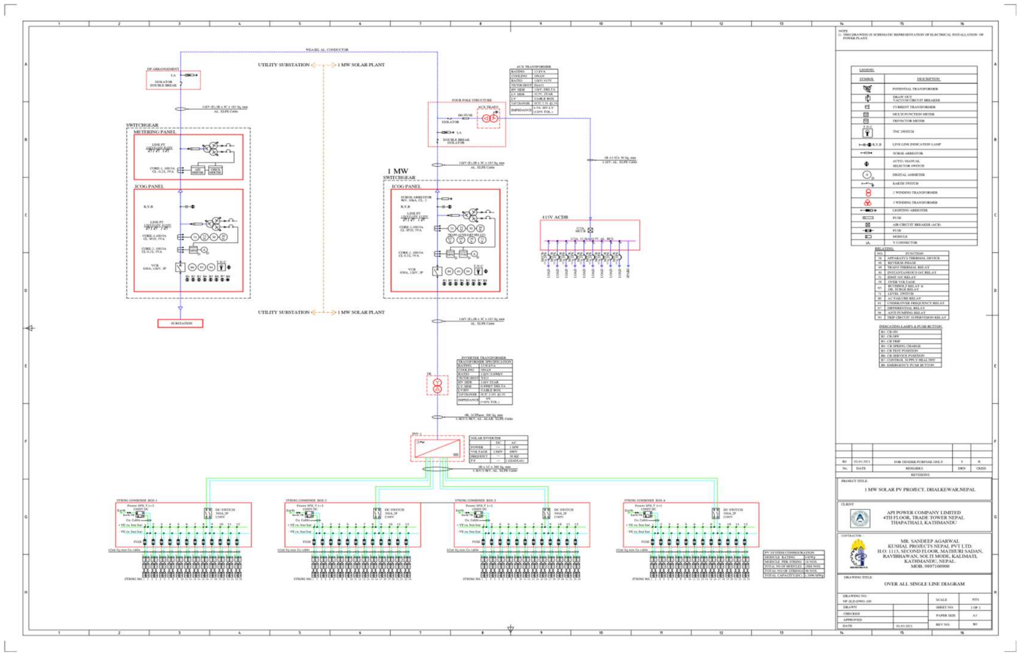

Figure: SLD of both the Plants

The electrical current, voltage and power level for different plant components are shown in table . Twenty Eight PV modules were connected in series to form a string and two such strings were connected in the parallel to get connected to the bus bar of SCB, total no of strings connected in parallel in 1 SCB is 24. 96 numbers of string were combined to feed the inverters through 4 inputs, 24 strings in 1 input.

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 1.2096 MWP DC for both Dhalkebar and Simara Plants, while the transformer nominal rating is 1.25 MVA. For utilization of the maximum power of 1000 kW that the inverter could produce, the transformer needs to operate with an underloading of about 20 %.

Particulars	**Quantity**	**Parameter**	**Value**	**Total**
PV Modules in series to form string	28	Voltage (V_p)	41.5	1162
		Current (I_p)	10.85	10.85
		Power (W_p)	450	12600
PV strings DC input to Inverter	96	Voltage (V_p)	1162	1162
		Current (I_p)	10.85 x 96	1041.6
		Power (kW_p)	96 x 12.6	1209.6

Nominal AC output from inverters at UPF	1	Voltage (V_L)	690	690
		Current (I_L)	875	875
		Power (kW)	1000	1000
Input to transformer primary windings at UPF	2	Voltage (V_L)	690	690
		Current (I_L)	875	875
		Power (kW)	1000	1000
Nominal output from transformer secondary winding at UPF	1	Voltage (V_L)	11000	11000
		Full load Current (I_L)	65.61	65.61
		Power (kW)	1250	1250

Annex C: PV Module and SCB connection

The solar modules used were Monocrystalline Longi Module, each rated 450 Wp at STC. There were 2,688 identical solar modules used, thus comprising a system of a total capacity of 1.2096 MWp. The detailed technical description is shown in table below.

Particulars	**Values**
Manufacturer/Model/Technology	LR4-72HPH-450M
Country of origin	China
Rated Capacity	450 W_p
Voltage at maximum power (V_{mpp})	41.5 V
Current at maximum power (I_{mpp})	10.85 A

Open circuit Voltage (V_{oc})	49.3 V
Short circuit current (I_{sc})	11.6 A
Module Size (mm)	2094 x 1038 x 35
No. of Modules	2688
Total Modules Area	5842.56 m^2
Efficiency	20.7 %
Temperature coefficient of P_{mpp}	-0.350 %/°C
Temperature coefficient of Voc	-0.270 %/°C
Temperature coefficient of Isc	0.048 %/°C

As shown in figure 11, 28 modules were connected in series to form a string. The voltage becomes about 1162 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 between. Here, 1 in four SCB and it's connection to strings is shown in figure 11. There are 4 such SCBs connected to one central Inverter.

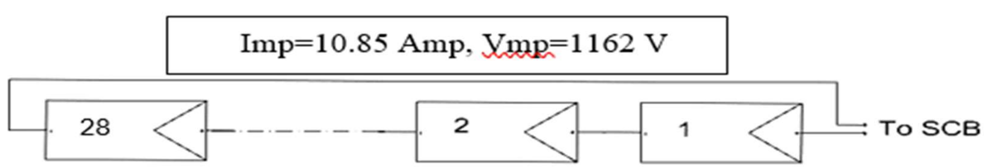

Figure: Panels connection in String

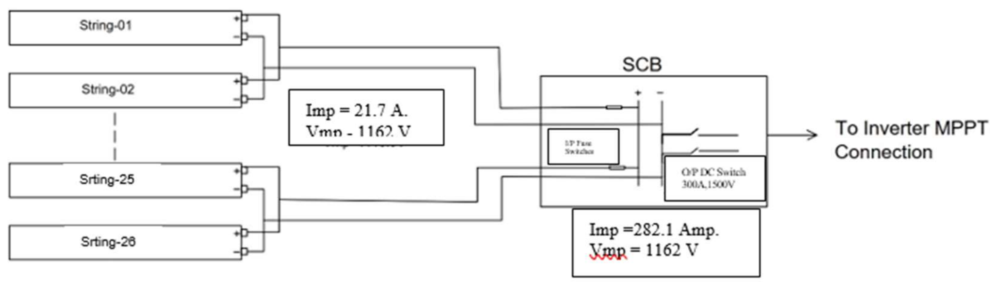

Figure: String Connection to SCB

Annex D: Inverter

An inverter having a maximum output capacity of 1000 kW was used. Table 5 shows the detailed specification of the inverter. It should be noted that output decreases with increasing temperature as the inverter output is rated for 1045 kVA at 50°C. As shown in figure 5, Inverter is fed with total of 4 inputs with each of 24 strings.

Particulars	**Values**
Manufacturer/Model	PVS980-58-1045KVA-L
Country of origin	India
Rated Input Power (DC)	KWp
MPP Voltage Range	978 V to 1100V
Maximum Input current	1200 A
Rated Output Power at nominal AC voltage	1150 kVA @ 35°C 1045 kVA @ 50°C
Nominal AC voltage	3/PE, 690V (+10%)
Rated Output Current	875 A
Efficiency	98%

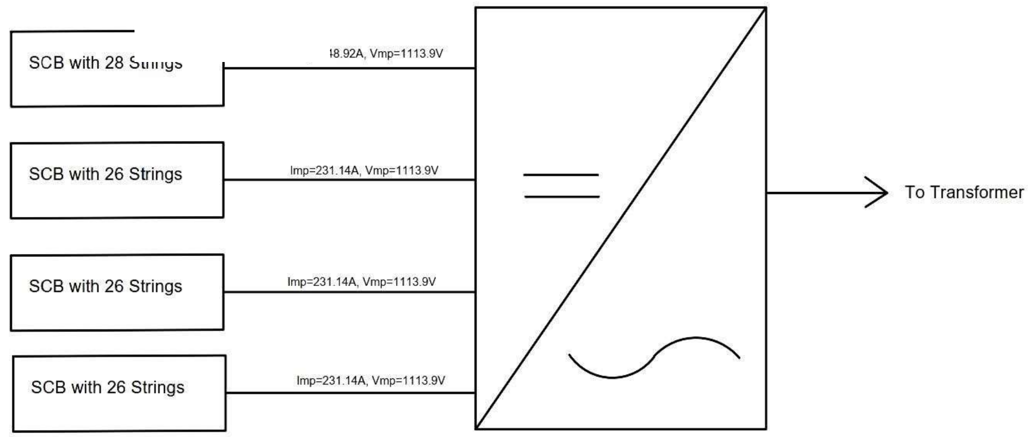

Figure: SCBs' connecton to Inverter

Annex E: Transformer

Table 6 shows transformer specifications. Its rated capacity is 1.25 MVA with a voltage level of 11/0.69 kV.

Particulars	**Values**
Manufacturer/Type	TMC India/Oil Cooled Copper Wound
Country of origin	India
Capacity	1250 KVA
Voltage	11×0.69 kV
Current	65.61×1045.92 A
Impedance	6.40%
Type of Cooling	ONAN

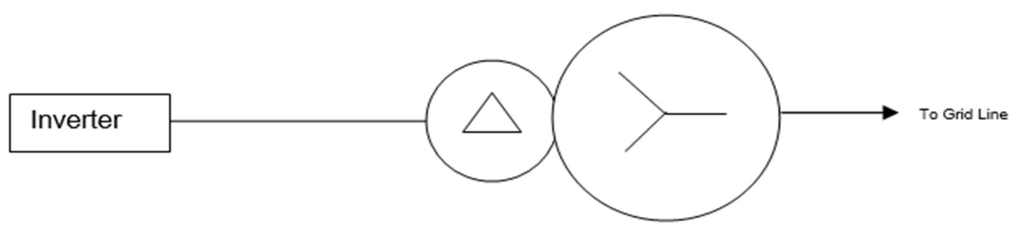

Figure: Inverter's Connection to Transformer

Annex F: Other accessories

- Combiner Box

There were in total 4 combiner boxes, where the strings of PV modules are attached. Inverter is fed with 4 outputs coming from four combiner boxes.

Array in 1 SCB consists of 672 PV modules with 24 strings in parallel and 28 modules connected in series in each string.

- Safety Provision

- 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 variousfailure conditions. Some of the protection devices are listed in table below,

S.N.	Description	Protection Device	Rating
1.	Array Combiner Box input side	Fuse	30A, 1500V
2.	Array Combiner Box output Side	Disconnector	300A, 1500V

- 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.

- 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 warnsbefore the situation changes from bad to too worse. Carbon dioxide type fire extinguisher is made available in case of fire.