TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

THESIS NO: M-187-MSESPM-2021-2025

Energy Deficit Compensation using Solar Hydro Hybrid System: A Sustainable Approach for Nepal's Power Sector

By

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A THESIS REPORT

SUBMITTED TO THE DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN ENERGY SYSTEM PLANNING AND MANAGEMENT

DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

LALITPUR, NEPAL

APRIL, 2025

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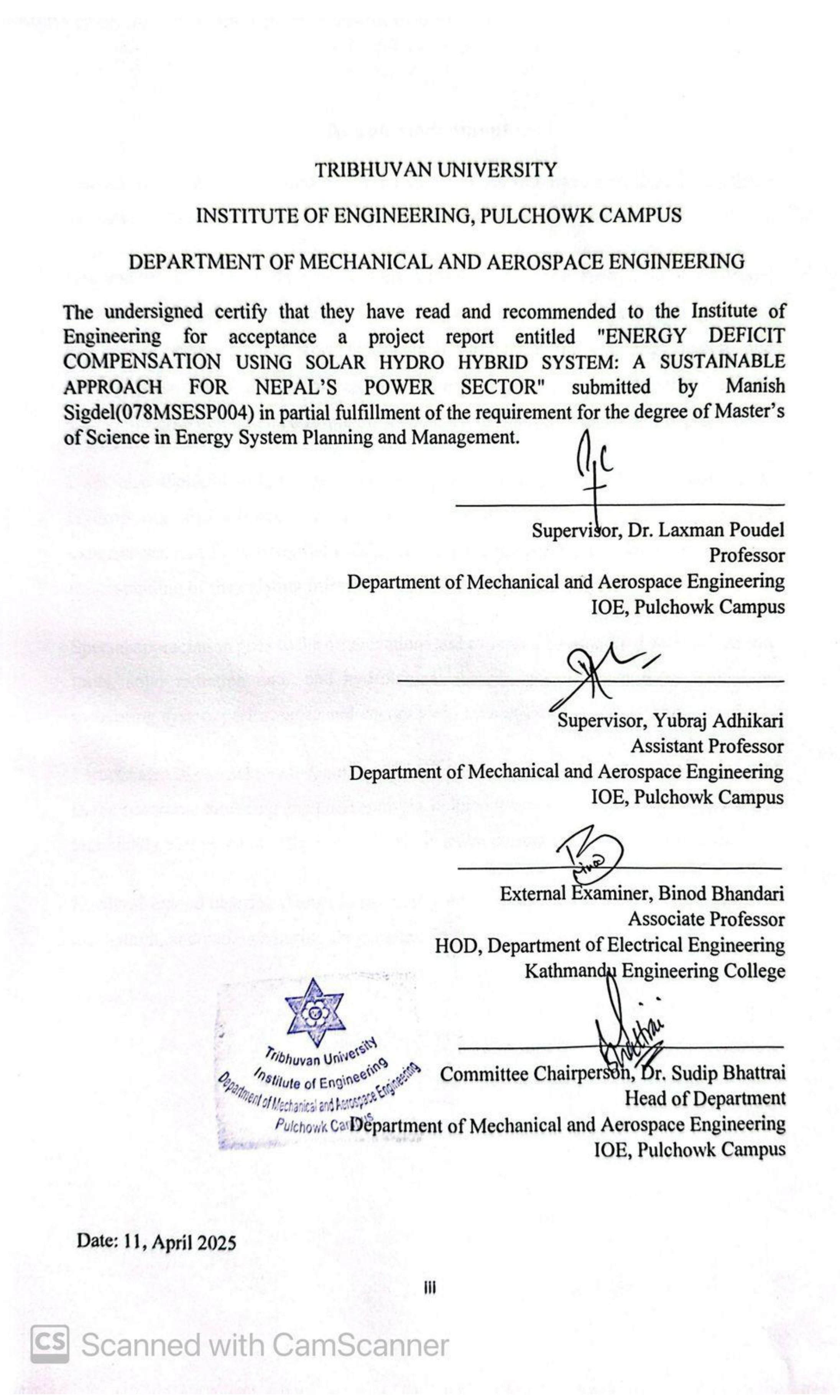

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The undersigned certify that they have read and recommended to the Institute of Engineering for acceptance a project report entitled "ENERGY DEFICIT COMPENSATION USING SOLAR HYDRO HYBRID SYSTEM: A SUSTAINABLE APPROACH FOR NEPAL'S POWER SECTOR" submitted by Manish Sigdel(078MSESP004) in partial fulfillment of the requirement for the degree of Master's of Science in Energy System Planning and Management.

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Acknowledgement

I would like to express my sincere gratitude to all those who have contributed directly or indirectly to the successful completion of this thesis

First and foremost, I extend my deepest thanks to my supervisors Prof. Dr Laxman Poudel and Assistant Prof. Yubraj Adhikari, whose expert guidance, technical insights, and continuous encouragement were instrumental throughout the planning, design, and feasibility analysis of this hybrid renewable energy system. Their constructive feedback and attention to detail helped refine the technical and financial aspects of the project.

I am also thankful to the entire engineering and support team at the Indrawati III Hydropower Project site for providing essential data, sharing their operational experiences, and facilitating field visits, which gave me practical exposure and a better understanding of the existing infrastructure and its potential for hybrid integration.

Special appreciation goes to the organizations and experts who supported with simulation tools, solar radiation data, and hydrological records, all of which were critical in evaluating system performance and energy yield estimations.

I would also like to acknowledge the valuable inputs of financial consultants who assisted in the economic modeling and tariff analysis, helping to ensure that the project is not only technically viable but also financially feasible under current regulatory frameworks.

Finally, I extend heartfelt thanks to my family and friends for their unwavering support, motivation, and patience during the course of this work.

Thank You.

Abstract

The growing adoption of solar photovoltaic (PV) technology presents a valuable opportunity for Nepal to enhance the reliability and sustainability of its energy sector. This study investigates the technical and economic feasibility of a hybrid energy system by integrating a 4 MWAC Solar Power Plant (SPP) with the existing 7.5 MW Indrawati III Hydropower Plant (HPP), located in the Sindhupalchowk district of Bagmati Province.

The research is motivated by Nepal’s continued reliance on run-of-river (RoR) hydropower, which is highly vulnerable to seasonal discharge variations—particularly during dry months—resulting in significant energy deficits and increased dependency on electricity imports.

Using detailed simulations in PVSYST software, the study analyzes various hybrid configurations to determine the optimal model capable of serving maximum electrical demand under varying water level conditions. The hybridization of solar PV with hydropower—and additionally with pumped hydro storage—was evaluated for its ability to maintain grid stability, improve overall generation efficiency, and reduce energy shortages throughout the year. Economic analysis was also conducted to assess the costeffectiveness and financial viability of the integrated system.

The findings clearly demonstrate that solar-hydro hybrid systems can significantly enhance Nepal’s energy reliability and optimize renewable energy utilization, particularly during hot and dry seasons when hydro generation is limited. Moreover, the inclusion of pumped hydro storage offers an effective solution for storing surplus solar energy and shifting it to meet peak demands. The study concludes that strategic investment, supportive government policies, and advances in energy storage and grid integration technologies are essential for the successful implementation of hybrid systems. Ultimately, the hybrid energy model offers a resilient and sustainable pathway for Nepal to achieve energy self-sufficiency and long-term energy security.

CONTENTS

List of Figures

List of tables

1. INTRODUCTION

1.1 Background

Nepal's hydropower-dominated energy sector faces seasonal fluctuations, leading to significant energy deficits, particularly in the dry season. Nepal's power generation is heavily reliant on run-of-river (RoR) hydropower, which experiences seasonal variation due to fluctuating river discharge. During the dry season, reduced water flow causes energy deficits, leading to increased dependence on imports or alternative energy sources. Hybrid power plants are plants that generate electricity using a combination of multiple energy sources (as primary and auxiliary sources). Such power plants provide diversity and efficiency in energy production by integrating renewable energy sources in addition to the primary energy source.

A total generation capacity in the last FY reached 3,157 MW with the commissioning of new projects equivalent to the capacity of 473 MW(NEA). NEA’s hydropower plants generated 2,911 GWh of electricity in the year, a slight decrease from the previous years’ 2,930 GWh. The energy purchased from Independent Power Producers (IPPs) and NEA’s subsidiaries was 6,564 GWh and 2,597 GWh. Out of the total available energy, NEA and its subsidiaries contributed 39.43%, whereas import from India and purchase from domestic IPPs accounted for 13.57% and 47.00% respectively. The contribution of the domestic generation to the total available energy has remained approximately the same with a slight increase from 85.18% in FY 2022/23 to 86.43% in FY 2023/24 (2).

Nuwakot Solar Power Station is the largest solar plant of Nepal. The solar panels are installed in six locations within the premises of Devighat Hydro Power Station owened by Nepal Electricity Authority. Energy Generated from the plant is connected to the 66 kV sub-station of Devighat Hydropower Station. Total capacity of all 17 projects is estimated to be 110.47MW (Rodriguez, 2023). The growth of floating solar photovoltaic (PV) installations around the world is driving the development of hybrid renewable systems, combining solar panels with hydropower plants on reservoirs. Hydropower generation is the largest form of renewable energy capacity around the world, accounting for 1.3TW of the 2.8TW total in 2020, according to the International Renewable Energy Agency (IRENA). And hydro capacity is expected to grow further in the coming years. What’s more, around a third of hydropower capacity is run-of-river generation while the rest is reservoir-based, providing scope for a large volume of solar installation. The surface area of hydropower reservoirs around the world has the potential to host more than 4.4GW of floating PV panels at 2% surface coverage, generating around 6,270TWh of electricity. This is key for small nations with limited land availability for utility-scale solar installations, such as Singapore. Hydropower reservoirs also offer an advantage for solar projects in that they already have connections to the power grid as well as local infrastructure such as roads for site access. Installing solar PV at reservoir-based plants increases the flexibility of both forms of generation. It works by creating a "virtual battery" by supplying solar electricity during peak daylight hours, while balancing the grid with hydropower during times of low solar irradiation and overnight. Solar power will typically rise during the dry season, when reservoir levels are likely to be lower (Rodriguez, 2023). In some countries reliant on hydropower, climate change is seeing an increase in drought conditions that is reducing hydropower output and threatening blackouts. By covering the surface of a reservoir, floating solar panels reduce water evaporation. This has the effect of increasing water availability by around 6.3% and boosting hydroelectric generation by more than 140TWh. At the same time, placing PV panels on water has a cooling effect that increases their efficiency (Rodriguez, 2023).Installing hybrid power plants into existing power plants as an auxiliary source is relatively less costly than building a new power plant. Hybrid systems built on existing electrical infrastructure reduce operation and maintenance costs and contribute to energy diversity and increased energy efficiency. In order for a project to be considered as an investment instrument, it is important to conduct a detailed economic analysis and to provide a clear path for the investor in terms of viability. There are many software tools with different features available in the literature for the techno-economic evaluation of hybrid powe plants (3). The most widely used ones are Solarius PV, SAM (solar advisor model), PVsyst, PVWatts, PVGIS (photovoltaic geographic information system), HOMER (Hybrid Optimization Model For Electric Renewable Resources), SolarGIS, PVSOL,RETScreen, BlueSol, HelioScope, PolySun, Solar Pro.

The integration of solar power and pumped hydro storage represents a significant advancement in renewable energy technology. This innovative approach combines the strengths of solar photovoltaic (PV) systems with the energy storage capabilities of pumped hydroelectricity, offering a sustainable and reliable solution for meeting the world’s growing energy demands. At its core, the integration of solar and pumped hydro storage involves capturing solar energy using photovoltaic panels and storing excess electricity in the form of potential energy in water reservoirs. During periods of high solar energy production or low electricity demand, surplus energy is used to pump water from a lower reservoir to a higher elevation. When electricity demand rises or solar energy production decreases, the stored water is released, flowing downhill through turbines to generate electricity (Gupta, 2024).

Integration with Indrawati III Hydropower Plant

Indrawati III hydropower is taken as a sample project to study the energy generation variation, design a solar plant and integrate with the national grid. Since there is plenty of available land to install.

Figure 1 Indrawati III site

Figure 2 Indrawati III site

Indrawati III Hydropower Project is a run-of-river (RoR) hydropower plant developed by National Hydroopower Company in 2059 BS. It is located melamchi-09, Sindhupalchowk, Nepal. It utilizes the flow of the Indrawati River, a tributary of the Sunkoshi River, to generate electricity. The project is designed with an installed capacity of 7.5 MW and supplies power to the national grid through a Power Purchase Agreement (PPA) with Nepal Electricity Authority (NEA).

Table 1: Indrawati III HPP salient features

1.1.2 Hydrological Characteristics:

Parameter	Details

Location	Indrawati River, Nepal
Type	Run-of-River (RoR)
Installed Capacity	7.5 MW
Annual Energy Generation	~40 GWh (based on river flow)
Turbine Type	Francis Turbine
Head	~60m
Discharge	14.13m^3/s
Power Purchase Agreement (PPA) Rate	NPR 4.83/kWh
Grid Connection	66 kV transmission line to Panchkhal Substation

The plant operates based on the natural flow of the river, which means that power generation fluctuates throughout the year. During the monsoon season, from Asar to Bhadra in the Nepali calendar, the river experiences higher discharge due to increased rainfall, resulting in higher electricity generation. In contrast, during the winter months, from Mangsir to Falgun, the river flow decreases significantly because of reduced rainfall and potentially higher water usage for other purposes, leading to reduced power generation. As a result, the plant faces an annual energy deficit, which becomes more pronounced during the dry months when water availability is insufficient to meet energy demands, causing a shortfall in electricity production.

Overview of solar-pumped storage hydropower plant in an existing indrawati III hydropower project

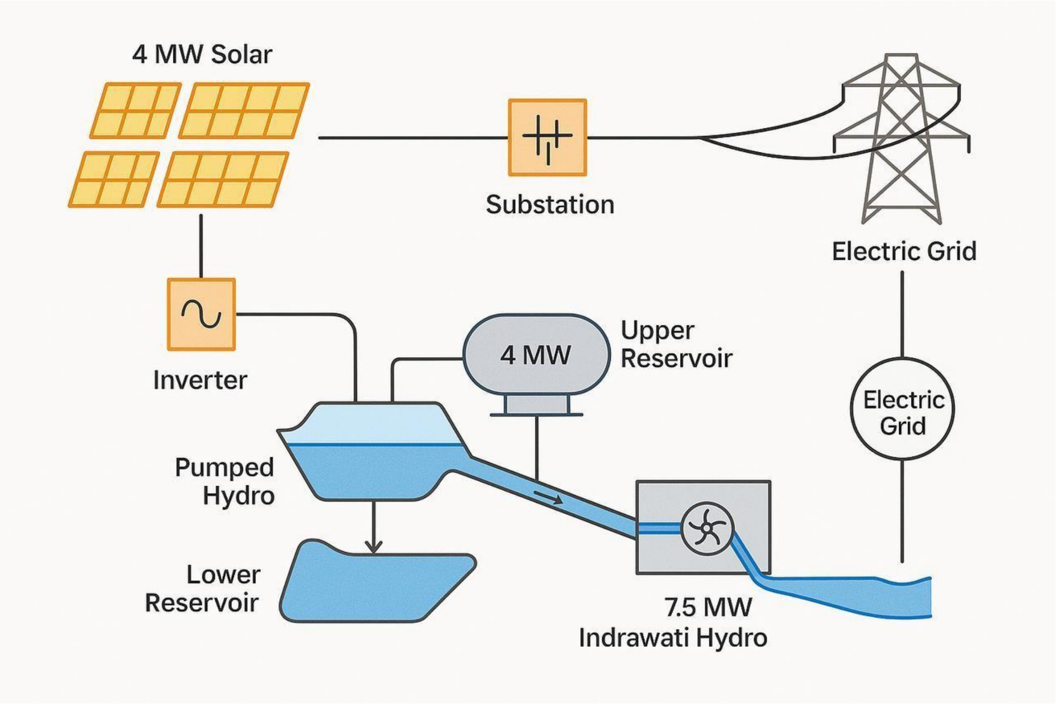


Figure 3 System Overview

The diagram presents a hybrid renewable energy system that integrates a 4 MW solar power plant, a 4 MW pumped hydro storage unit, and the existing 7.5 MW Indrawati Hydropower Plant. This system is designed to optimize energy generation, storage, and dispatch using renewable sources while ensuring stability and flexibility in power supply. During daylight hours, the solar plant generates electricity which is converted from DC to AC using an inverter. This electricity is either directly fed into the grid through a substation or used to operate pumps in the pumped hydro system. The pumped hydro mechanism utilizes excess solar energy to lift water from the lower reservoir to the upper reservoir, thereby storing energy in the form of gravitational potential energy. When energy demand rises—typically during evening or nighttime—the stored water is released back to the lower reservoir, driving turbines in the pumped storage unit to generate up to 4 MW of electricity.

Simultaneously, the 7.5 MW Indrawati Hydropower Plant continues to generate electricity from the river’s natural flow, operating independently but in coordination with the hybrid system. Both solar and hydropower outputs are connected to the grid, ensuring a stable and continuous supply of electricity. The configuration is efficient in flattening load curves by storing excess daytime generation and releasing it during peak demand. Furthermore, it utilizes the existing hydropower infrastructure, making the solution cost-effective and sustainable. This kind of integrated system is particularly well-suited to the topography and energy needs of Nepal, offering a reliable, renewable, and flexible approach to modern power generation and storage.

1.2 Problem statement

Nepal's energy sector heavily depends on hydropower, which experiences seasonal variations in generation due to fluctuating river flow. The energy deficit graph of Indrawati III Hydropower indicates a significant drop in power generation during certain months (Bhadra, Asad, Shrawan), leading to reliability issues and economic losses..

However, challenges exist in designing an optimal hybrid system, integrating it into the grid, and ensuring financial viability. This study aims to explore the technical and economic feasibility of a 4 MW solar-hydro hybrid system at Indrawati III Hydropower to reduce seasonal energy deficits and maximize revenue.

1.3. Objectives

1.3.1 Main Objectives

To study the feasibility of solar hydro hybrid energy to enhance generation of Indrawati III Hydropower Plant

1.3.2 Specific Objectives

i. To analyze historical generation data of Indrawati III Hydropower to identify seasonal shortages, losses.

ii. To design a 4 MWAC grid-connected solar system using PVSYST simulation and study the feasibility of pumped storage hydropower for peak hour demand.

iii. To evaluate solar-hydro and pumped storage hydropower complementarity for stable power output and analyze its financial feasibility.

1.4 Scope of work

The scope of work encompasses both technical and financial aspects of renewable energy assessment. The technical scope includes solar system design using PVsyst and pumped storage hydropower ensuring efficient energy generation and system optimization. It also covers hydropower generation assessment, analyzing monthly variations and grid contributions to evaluate energy availability. Additionally, hybrid energy modeling will be conducted to achieve optimal power balancing, integrating multiple energy sources for enhanced reliability. Furthermore, power evacuation and grid integration analysis will be carried out to assess the feasibility of transmitting generated power into the grid efficiently.

On the financial front, the scope involves capital and operational cost estimation to determine the overall investment required for project execution and long-term sustainability. Revenue modeling and tariff comparison will be performed to analyze potential earnings and pricing competitiveness. Moreover, financial feasibility analysis will be conducted, incorporating key indicators such as Internal Rate of Return (IRR), Net Present Value (NPV),

1.5 Significance of study

The significance of this study lies in its potential contributions to energy security, reliability, and economic benefits. By addressing seasonal power shortages at Indrawati III, the research helps ensure a more stable and consistent energy supply. The integration of solar and pumped storage hydropower enhances grid stability by providing a balanced energy mix, reducing fluctuations and improving overall system reliability.

From an economic perspective, the study highlights the financial advantages of a hybrid system. The Power Purchase Agreement (PPA) for solar energy, priced at Rs 8.5/kWh, offers higher revenue compared to hydropower, which is priced at Rs 12/kWh during peak hours in dry season. Additionally, the increased efficiency of the hybrid system leads to a faster payback period, making the project financially more attractive and sustainable in the long run.

2. LITERATURE REVIEW

The reviewed literature highlights the growing adoption of solar-hydro hybrid systems to enhance energy generation, grid stability, and economic viability. Studies have demonstrated that integrating solar power with hydroelectric plants improves efficiency, optimizes reservoir operations, and mitigates seasonal fluctuations in hydropower output. Research in various regions, including Brazil, China, India, and Bangladesh, has shown increased energy production, with floating photovoltaic systems significantly boosting hydroelectric output. Economic analyses indicate that while hybrid systems require high initial investment, they become cost-effective over time by reducing operational inefficiencies and maximizing energy generation. In Nepal, where hydropower dominates the energy mix, studies suggest that integrating solar PV can address seasonal deficits and improve grid reliability, making projects like Indrawati III strong candidates for hybrid integration.

Olkkonen and others (2023) discussed the sizing and planning of a hybrid-floating photovoltaic system. The study analyzed the techno-economic feasibility of the hybrid system under different conditions.

Dursun and Saltuk (2023) studied two scenarios for optimizing the installed capacity of a solar power plant in a hydro-solar hybrid model of an 18,777 MW hydroelectric power plant in Tokat and Resadiye district. In the first scenario, where no reservoir area was considered, the installed capacity of the solar power plant was calculated as 9,575 MW. In the second scenario, which considered the reservoir area, incoming water flows were adjusted to maximize solar power generation, leading to an installed power value of 20.9 MW.

Balan et al. conducted a solar hybrid modeling study of a cascade hydroelectric power plant on the Tiete River in Brazil. Their findings showed that the hybrid model increased production values and improved reservoir operating conditions. They also concluded that grid capacity limits the production value of the hybrid model. Saltuk's PhD thesis further highlighted that hydroelectric power plants generate lower output in summer due to reduced rainfall, whereas solar energy complements production by increasing generation during the same period. The study concluded that hydroelectricsolar hybrid modeling enhances power plant production capacity and prevents inefficiencies in transformer usage caused by seasonal production fluctuations. Mehadi et al. (2021) conducted a comprehensive analysis by simulating the installation of a 50 MW floating photovoltaic system in the reservoir area of Kaptai Dam, Bangladesh. Their study found a 10% increase in the power generation of the existing hydroelectric plant. They also determined that electricity generation could be optimized in different seasons using hybrid modeling. The hybrid system in Bangladesh outperformed similar models in China (Longyangxia Hybrid Power Plant) and Portugal (Alto Rabagão Hybrid Power Plant), achieving a capacity factor of 33.64% and full-load generation of approximately 2,944 hours.

Agyekum et al. (2022) researched a hybrid model integrating hydropower with battery storage (Scenario 1) and PV/Hydroelectricity/Battery (Scenario 2) for irrigation and electrification in a rural settlement in northern Ghana. Their results showed that Scenario 1 generated 1,095,679 kWh of electricity annually, while Scenario 2 generated 2,005,544 kWh. The operating cost for Scenario 1 was $18,318, compared to $22,606 for Scenario 2. Cazzaniga et al. (2019) investigated the integration of floating photovoltaic systems with hydroelectric power plants among the world's 20 largest hydroelectric facilities. Their study found that hydroelectric power generation increased by 65% when photovoltaic panels were installed on 10% of the reservoir area. Pianco et al. (2022) simulated a floating photovoltaic system covering 2.8% of the reservoir area of a hydroelectric power plant in Santa Branca, Brazil. They analyzed 20 years of hydroelectric production data and aimed to optimize energy generation by ensuring that photovoltaic systems operated during daylight hours. While the hydroelectric plant initially produced 4 TWh of electricity, the hybrid system increased this value by 50% to 6 TWh.

Anandhi et al. (2024) summarized the critical role and benefits of solar-hydroelectric hybrid systems in electricity generation. Hybrid systems provide a reliable energy source by balancing production and consumption, reducing dependence on traditional grids, and minimizing environmental impacts. Innovations in storage and control systems help address the inherent imbalances of renewable energy, increasing efficiency and optimizing performance. Economic analyses indicate that although hybrid systems require a high initial investment, they become cost-effective over time due to significant reductions in operating and investment costs.

Campos et al. (2021) highlighted the importance of hydroelectric reservoirs in arid regions, where water is essential for multiple purposes such as power generation, agriculture, and drinking water supply. During severe droughts, water demand for hydropower generation can reduce reservoir levels to critical points, increasing the risk of water scarcity. To mitigate this, the integration of solar energy, particularly floating photovoltaic systems, has been proposed as a solution to diversify energy production and reduce reliance on hydropower.

Several countries have successfully implemented solar-hydro hybrid projects, demonstrating their effectiveness in enhancing energy generation and grid stability. In China, the Longyangxia Dam Solar-Hydro Hybrid Plant, which combines 850 MW of hydroelectric capacity with 320 MW of solar power, has significantly improved energy efficiency and grid stability. This integration allows for better management of power fluctuations by complementing hydropower generation with solar energy during peak sunlight hours, ensuring a more stable electricity supply **(Wang et al., 2019).**

Similarly, Brazil has adopted hybrid systems, with a notable example being the Balbina Dam floating solar PV system. This system has helped offset seasonal hydro fluctuations, particularly during dry periods when water availability for hydropower generation is reduced. By utilizing the reservoir surface for solar power generation, the system not only maximizes energy production but also reduces transmission losses and minimizes water evaporation, contributing to overall energy security **(Pereira et al., 2020).**

In India**,** the Kadodra Solar-Hydro Hybrid Plant, with a capacity of 2 MW, has been implemented to provide a stable power supply throughout the year. Given India's reliance on monsoon-dependent hydropower, integrating solar energy has helped mitigate the impact of seasonal water shortages. The hybrid model ensures a consistent electricity supply by balancing solar generation during the dry season with hydroelectric power during the rainy season, making it a sustainable and reliable energy solution **(Ramesh et al., 2022).**

The integration of reversible pump turbine machines has increased the flexibility, response time and performance of PHS, however, hybridization of PHS with other storages can increase the range of services and overall system reliability, especially when RE systems are off-grid (Muhammad Shahzad Javed, 2020)**.**

3. RESEARCH METHODOLOGY

3.1 Research methods

This thesis is a quantitative study where after identifying the problem and conducting relevant literature study, the performance data from the sites were collected. The data were then analyzed, compared, and then relevant information brought out. Figure 1 shows the research methodology flowchart followed for this study.

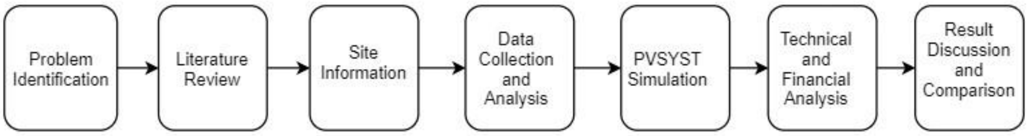


Figure 4: Flowchart of the methodology

3.2 Data collection

The data of hydropower energy generation of last five years of Indrawati III Hpp is taken for evaluating the energy generation as well as the energy deficit. Also the solar irradiance data is used.

3.2.1 Hydropower energy generation

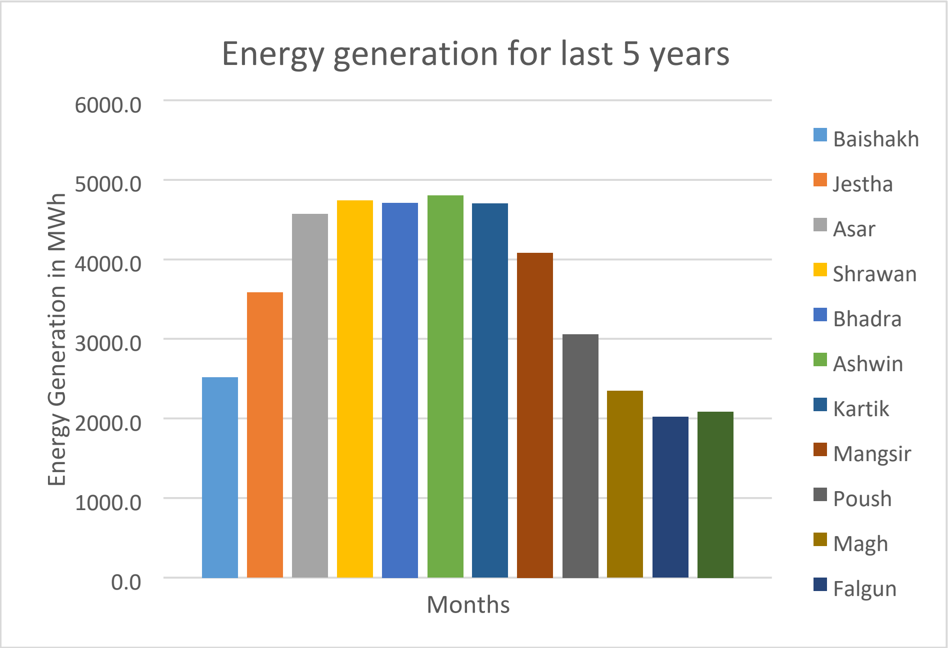


Figure 5: Energy generation for last 5 years

The bar chart represents the average energy generation over the last five years on a monthly basis (in MWh). The highest energy generation occurs between Asar, Shrawan, Bhadra, and Ashwin, with values reaching around 5000 MWh. This coincides with the monsoon season in Nepal (June - September), leading to increased river flow and higher hydropower generation. Energy generation starts to decline from Kartik onwards and by Poush and Magh (December - January), the generation drops to around 2000 - 2500 MWh due to reduced water availability in rivers.

Falgun, Chaitra, and Baishakh (February - April) show the lowest energy generation, around 2000 - 2500 MWh. This aligns with dry season months, where river flow is at its lowest. The energy generation pattern clearly shows high reliance on monsoon flow. The significant variation in energy production between monsoon and dry seasons highlights the need for a hybrid solution (such as integrating solar) to compensate for energy deficits during low-flow periods.

3.2.2 Energy Deficit:

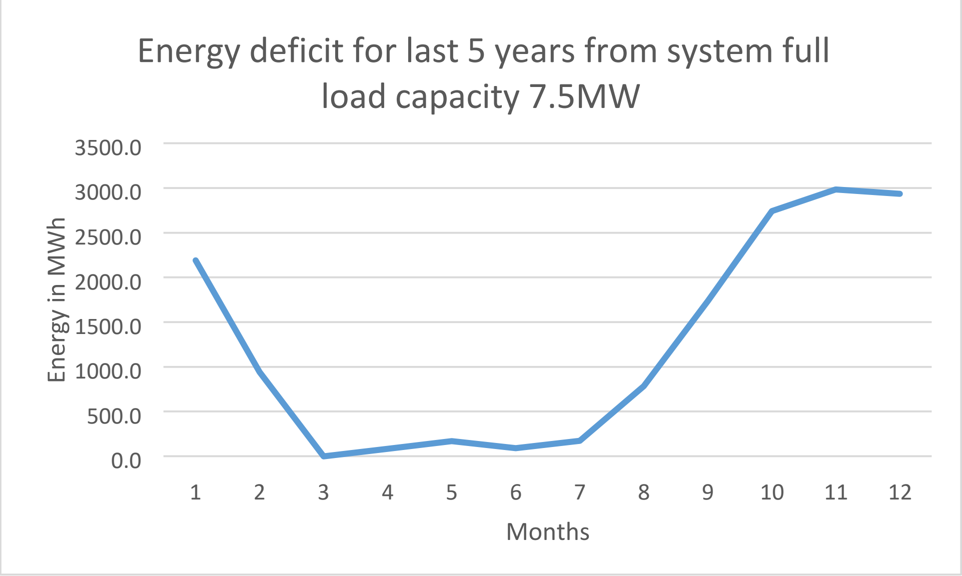


Figure 6: Energy deficit for last 5 years from system full load capacity 7.5 MW

The line graph illustrates monthly energy deficit (in MWh) over the last five years, considering a 7.5 MW full-load generation capacity. The deficit represents the shortfall between theoretical maximum generation and actual energy production due to seasonal variations in water flow. The significant energy deficits are observed in the months 10 (Ashwin), 11 (Kartik), and 12 (Mangsir), reaching up to 3000+ MWh. Similarly, the highest deficit appears in month 1 (Baishakh), exceeding 2000 MWh. These months coincide with the dry season, where river discharge is low, causing reduced hydropower output.

From month 3 (Asar) to month 7 (Bhadra), the energy deficit is minimal, nearing 0 MWh. This aligns with the monsoon season, where high water inflow allows the system to operate closer to its full capacity. This trend confirms that hydropower production is sufficient in wet months but struggles to meet demand in dry periods. The deficit starts increasing again in month 8 (Asoj) and peaks by month 10 (Kartik). This is due to receding river levels after monsoon, gradually limiting hydro generation.

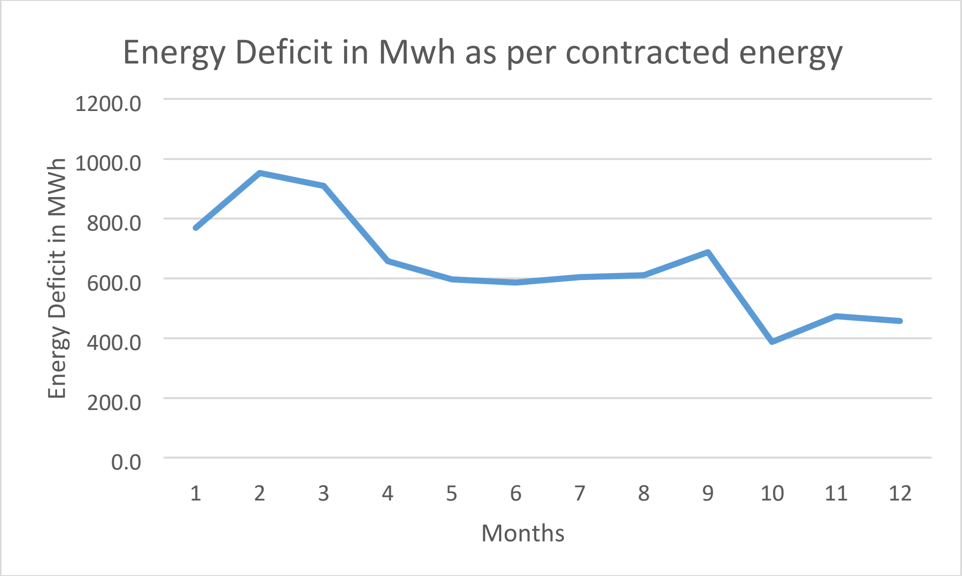


Figure 7: Energy deficit in MWh as per contracted energy

The graph illustrates the monthly energy deficit based on contracted energy agreements. The highest deviation occurs in Months Jestha & Asar, exceeding 900 MWh, indicating a significant shortfall in meeting contracted supply. The deficit drops gradually and stabilizes around 600 MWh during this period. The deficit reaches its lowest point (~400 MWh) in Month Magh, suggesting improved energy availability. A slight increase in deficit follows, likely due to reduced hydro generation after monsoon.

3.3 Grid tied PV- Hydro Overview:

The PV system consists of solar panels and grid-tied inverter, are the central components of the system. Variables like air temperature, wind speed, and solar irradiation are measured, which affect the performance of solar panel. The measured solar irradiation gives the reference yield based on which the yield of solar panel can be compared. The DC output of the panel gives the array yield, while the AC output gives the final yield; which is always less than the array yield because of inverter efficiency. The final energy output can be used to determine performance parameters such as final yield, performance ratio, capacity utilization factor, and system efficiency.

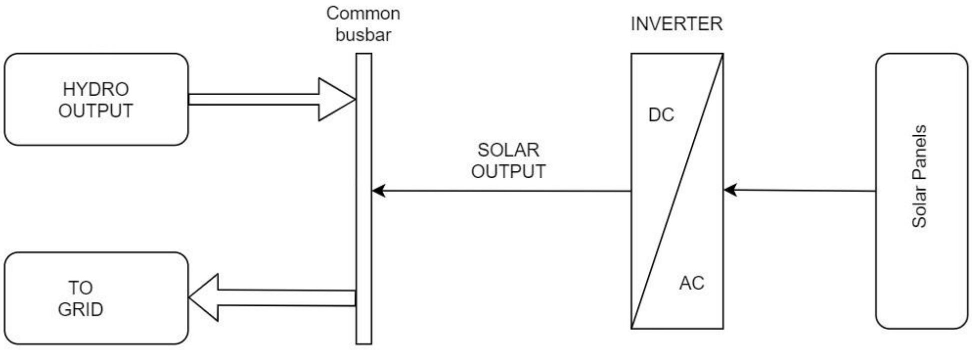


Figure 8 Grid tied PV-Hydro overview

3.4 PVSYST Software for Solar design

PVsyst is one of the most widely used software for the design, simulation, and analysis of photovoltaic (PV) systems. It is specifically designed for grid-connected, off-grid, and hybrid solar power plants, making it an essential tool for solar engineers, consultants, and project developers. The software provides detailed insights into system performance, energy yield, losses, and economic analysis, helping in the optimal design of solar projects.

3.4.1 Performance assessment parameters

The assessment of grid-tied solar PV systems is necessary to evaluate their performance in various climatic regions and to identify issues associated with their operation. Parameters such as array yield, final yield, performance ratio, capacity utilization factor, and system efficiency were calculated to help in the assessment.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}} \right) \left[1 + \alpha_p \left(T_c - T_{c,STC} \right) \right] \qquad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(i)}$$

Array yield

Array yield is the ratio of direct current energy output from the PV array over a certain period to its rated power. It indicates the number of hours that the PV array must operate at its nominal power to generate the energy produced (Owolabi et al., 2022). It is given by,

$$Ya = \frac{E_{DC}}{P_{STC}} \text{ (kWh/kWp) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(ii)}$$

where E_{DC} is the direct energy (DC) energy output from the PV array and PSTC is the installed power at STC.

Final yield

Final yield is the ratio of net energy output of the entire PV system to its rated power. It indicates the duration in hours the PV array must operate at its nominal power to produce the recorded amount of energy. It is given by

$$Yf = \frac{E_{AC}}{P_{STC}} \text{ (kWh/kWp) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_(iii)}$$

energy output and PSTC is the installed power at STC conditions. Usually, the specific yield (array yield and final yield) [kWh/kW$_P$] is used to evaluate the solar PV system performance but it does not consider the footprint of the system. As rooftop area comes as a design constraint in most of the cases, specific yield per unit area (kWh/m^2) is also used as an important indicator for comparing solar PV systems (Ayadi et al., 2022).

Reference yield

The reference yield is the ratio of total in-plane solar radiation, H_T (kWh/m2) to the reference irradiance at STC, G_{STC} (kW/m^2). It is given by

$$Yr = \frac{H_T}{G_{STC}} \text{ (kWh/kWp) \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ (iv)}$$

It represents an equivalent number of hours that the system need to operate at the reference irradiance (Roumpakias & Stamatelos, 2017) and defines the amount of solar radiation for the

PV system (Marion et al., 2005). 3.3.4. Performance ratio ne performance ratio (PR) measures the quality of a solar photovoltaic and is independent of location (Verma & Singhal, 2015). It indicates how close a PV system is to its ideal performance during actual operation and allows PV systems comparison independent of location tilt angle, orientation, and nominal power capacity (Sharma & Goel, 2017). It is given by,

$$PR = \frac{Y_f}{Y_r} \times 100\% \quad \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \text{(v)}$$

By normalizing with irradiance, it quantifies the overall effect of losses on the rated output due to ineffictency of inverter, wiring losses, PV module temperature, dust accumulation, system d0%n-time, and component failures (Marion et al., 2005). It does not represent the amount of energy produced, as a system with low PR in high solar resource location can produce more energy than a system with high PR in low solar resource location. Gopi et al. (2021) compared normal and weather-corTected PR of PV solar plants in hot and cold climates and found that weather-corrected PR is important for colder areas than warmer areas. The weather-corrected

PR of Montana (annual average temperature of 1.58 ^{o}c) PV plant had maximum variation of 7.64% during summer and -8.61% during winter, whereas the weathercorrected PR of Kuzhalmannam (annual average temperature of 27.28 ^{o}c), PV plant had maximum variation of i .16% during summer and -0.91% during rainy.

Capacity utilization factor

Capacity utilization factor (CUF) is "the ratio of AC energy produced by the PV system over a given period (usually one year) to the energy output that would have been generated if the system were operated at full capacity for the entire period" (Adaramola & Vagnes, 2015)It is given by,

$$CUF = Yf = \frac{E_{AC}}{P_{STC} \times 8760} \times 100\% \quad \_\_\_\_\_\_\_\_\_\_\_\_ \text{(vi)}$$

System Efficency:

System efficiency is the ratio of AC output energy generated to the total possible energy that can be generated from the surface area of the solar panel. It is given by,

E^{AC}

η_{sys} = H ______ $T \times Am$ × 100%

____(vii) where A^m is the module area in m^2.

PV Cell Temperature

It is the temperature of the solar cell. At night, the value is same as the ambient temperature, while at day, the value can exceed the ambient temperature by 30^0C or more. Using the energy balance equation for PV array given by Duffie & Beckman (1991), the PV cell temperature is calculated by HOMER ENERGY (n.d.) as:

$$T_c = \frac{T_a + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left[1 - \frac{\eta_{mp,STC}\left(1 - \alpha_p T_{c,STC}\right)}{\tau\alpha}\right]}{1 + \left(T_{c,NOCT} - T_{a,NOCT}\right)\left(\frac{G_T}{G_{T,NOCT}}\right)\left(\frac{\alpha_p \eta_{mp,STC}}{\tau\alpha}\right)} \text{ ---------------- (viii)}$$

where, T_c = PV cell temperature

$T_{c,\ NOCT}$ —Nominal operating cell temperature

$T_{c,}$ = Cell temperature under standard test condition = 25^0C

T_a = Ambient temperature

$T_{a,\ NOCT}$ = Ambient temperature at which the NOCT is defiτned = 20^0C

G_T = Solar radiation striking the PV array [kW/m^2]

$G_{T.\ NOCT}$= Solar radiation at which NOCT is defined = 800 W/m^2 $\eta_{mp,stc}$ = Maximum power point efficiency under standard test condition α_p = temperature coefficient of power τ= solar transmittance of any cover over the array α= solar absorptance of the PV array

The loss in power generation is then calculated using the relation:

$P_{corrected} = P_{rated} \{1 + \alpha_p (Tc — Tc, STC)\}$ ________________________________(ix)

where,

P_{rated} = rated power of the solar panel

$P_{corrected}$ = Corrected power of the solar panel after temperature is considered.

3.5 Pumped storage hydropower design consideration:

- Pumping power = 4 MWAC (matched to solar) •

Efficiency (pumping mode) = 75% (G. Notton, 2011)

Water volume required per day (6 hours of pumping):

$E=P.t=4$ MW.6 hr=24 MWh

Water volume needed

$$V = \frac{E \cdot 3600}{\rho \cdot g \cdot H \cdot \eta}$$

:

V = Volume of water in cubic meters (m^3)

E = Energy in megawatt-hours (MWh) ρ =

Density of water = 1000 kg/m^3 g =

Acceleration due to gravity = 9.81 m/s H =

Head = 60 meters η = Overall efficiency =

0.75

3600 = Conversion factor from hours to seconds (1 hour = 3600 seconds) substituting the values:

$$V = \frac{24 \times 10^6 \times 3600}{1000 \times 9.81 \times 60 \times 0.75}$$

$$V \approx \frac{86,400,000,000}{441,450}$$

$$V \approx 19,090 \text{ m}^3$$

To store 24 MWh of energy at 60 meters head with 75% efficiency, approximately 20000 cubic meters of water is required in the upper reservoir.

3.6 DiGSILENT power factory

DIgSILENT GmbH is an independent software and consulting company providing highly specialised services in the field of electrical power systems for transmission, distribution, generation, industrial plants and renewable energy. DIgSILENT's innovative product portfolio comprises power factory, StationWare and monitoring systems.

3.6 Technical Analysis of proposed solar on the generation variation of Indrawati III HPP

To mitigate seasonal energy deficits in Indrawati III Hydropower (7.5 MW), a 4 MW solar PV plant is designed. Below is a detailed description of the solar plant along with relevant formulas for energy estimation and system design. PVSYST Software is used to model the required capacity of solar plant.

Table 2: Design parameters

Parameter	Value/Estimate
Installed Solar Capacity	5 MW
Annual Energy Generation	6820.868 MWh
Solar Panel Type	Monocrystalline
Inverter Type	String/Central Inverters (98% Efficiency)
Mounting Structure	Fixed Tilt
Grid Connection Voltage	66 kV (same as Indrawati III Hydropower)

Energy Generation Calculation

$E=P\times H\times P$

Where:

- **E** = Annual Energy Output (kWh)
- **P** = Installed Capacity (kW)
- **H** = Solar Irradiation per day (kWh/m²/day)
- **PR** = Performance Ratio

3.6.1 Solar Resource Data: Irradiation data for the project location.

The deficit is highest when solar radiation is also at its peak (Baishakh - Mangsir). The integration of a solar PV system can compensate for this hydro shortfall, ensuring stable energy availability throughout the year.

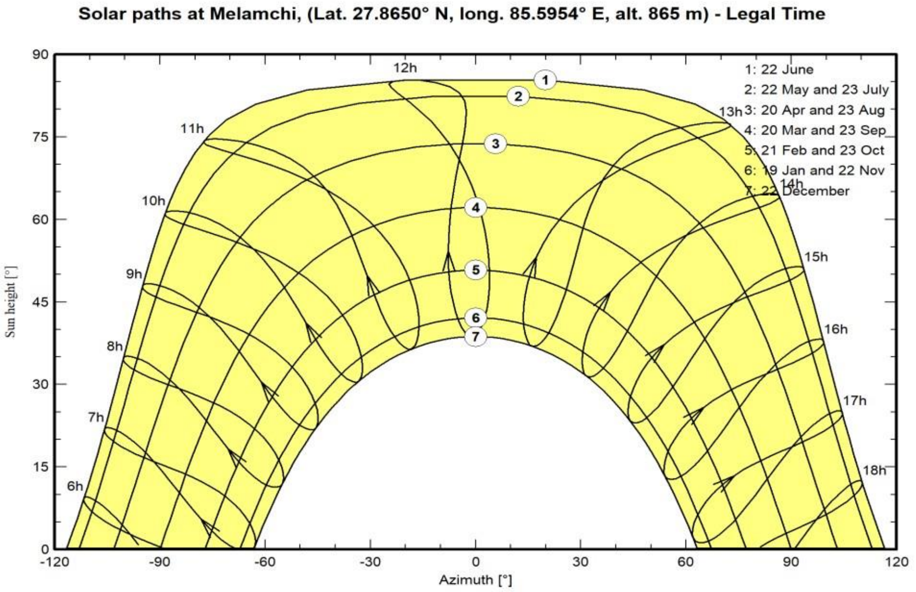
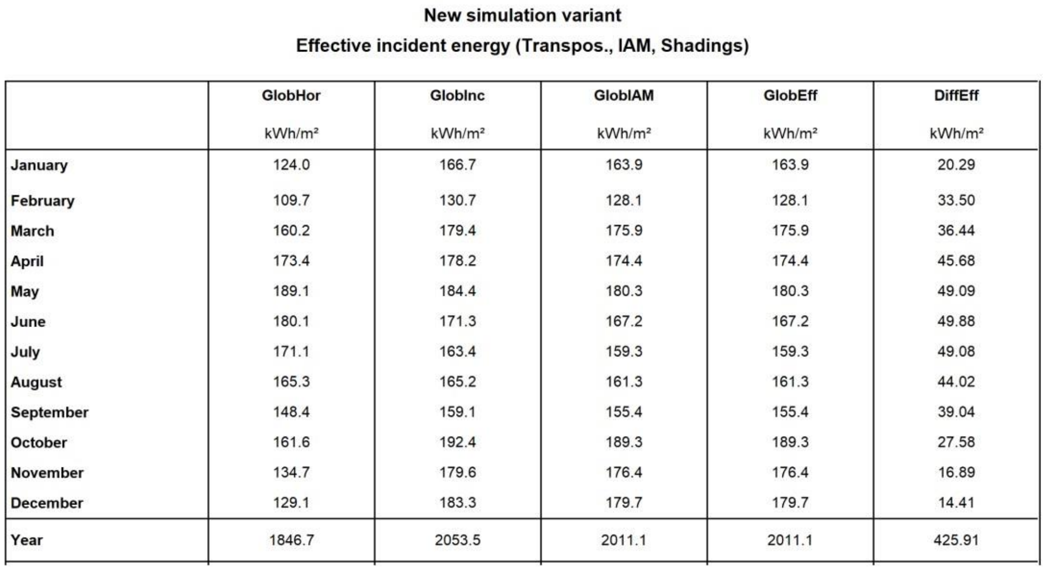


Figure 9: Solar paths at Melamchi

The solar altitude is highest in June and lowest in December, demonstrating the seasonal variations in sunlight. The sunrise and sunset positions shift throughout the year, with longer daylight hours in summer and shorter in winter. This graph is useful for solar panel positioning, agriculture planning, and energy generation analysis.

3.6.2 Site Monthly Irradiation Data

Table 3: Monthly irradiation



New simulation variant

Effective incident energy (Transpos., IAM, Shadings)

	GlobHor kWh/m²	GlobInc kWh/m²	GlobIAM kWh/m²	GlobEff kWh/m²	DiffEff kWh/m²
January	124.0	166.7	163.9	163.9	20.29
February	109.7	130.7	128.1	128.1	33.50
March	160.2	179.4	175.9	175.9	36.44
April	173.4	178.2	174.4	174.4	45.68
May	189.1	184.4	180.3	180.3	49.09
June	180.1	171.3	167.2	167.2	49.88
July	171.1	163.4	159.3	159.3	49.08
August	165.3	165.2	161.3	161.3	44.02
September	148.4	159.1	155.4	155.4	39.04
October	161.6	192.4	189.3	189.3	27.58
November	134.7	179.6	176.4	176.4	16.89
December	129.1	183.3	179.7	179.7	14.41
Year	1846.7	2053.5	2011.1	2011.1	425.91

The table presents a detailed breakdown of monthly and annual solar irradiance values, measured in kilowatt-hours per square meter (kWh/m²), based on a new simulation that accounts for transposition, incidence angle modifiers (IAM), and shading effects. It includes five key indicators: Global Horizontal Irradiance (GlobHor), Global Irradiance on the Inclined Plane (GlobInc), IAM-corrected Irradiance (GlobIAM), Effective Irradiance (GlobEff), and Effective Diffuse Irradiance (DiffEff). GlobHor represents the solar energy received on a horizontal surface, while GlobInc adjusts this value based on the tilt angle of the solar panels. GlobIAM and GlobEff further refine the data by incorporating losses due to the angle of incidence and shading, ultimately reflecting the actual usable solar energy for electricity generation. DiffEff indicates the portion of effective irradiance that comes from diffuse sunlight. The data shows that the highest irradiance values occur during April and May, suggesting optimal solar energy generation during these months, while the lowest values are seen in the winter months of December and January. Annually, the effective irradiance (GlobEff) totals 2011.1 kWh/m², highlighting the overall solar energy potential of the location under study. This data is essential for evaluating photovoltaic system performance, optimizing panel orientation, and estimating energy yields.

3.6.3 Solar PV Technology Selection & Assessment

Solar PV Modules and Inverters are the key components of any grid connected solar PV power plant. The global overview of solar PV technologies has been presented in the study. The inter comparability of all technologies has been made qualitatively as well as quantitatively. Mono crystalline PERC solar PV module technology has been observed best option for Grid Connected Solar PV Project. String inverters has been selected so far for 4 MW AC to maintain the redundancy and ease of installation. String inverters are highly efficient.

Table 4: Selection of Technology

1	PV Panel	TSM-600Wp
2	Panel Technology	Bifacial Monoperc
3	Inverter Size	SG320HX-20A 3 125 kW
4	Inverter Technology	String inverter

PV Panels & Inverters are manufactured by Trina Solar and Sungrow (one of the largest global inverter manufacturers) has been selected for basic designing of the Solar PV Project.

3.7 Energy Yield Estimation

The energy yield estimation has been made of the project size of 4 MW AC capacity under the cases of using mono PERC bifacial technology. The simulation exercise provides the base of sizing the plant and hence the land selected area is. The energy yield estimation has been carried out through PVSYST computer software. The tilt and orientation along with inter row spacing will be optimized in later on stages. The tilt angle of 20 degree towards equator (i.e.south) has been observed optimum.

3.7.1 Solar Inverter – Sungrow SG320HX-20A (125 kW)

Using mono-crystalline PERC solar PV technology the capacity utilization factor (CUF) of the 4970 MWDC project at oversizing of 20% In PV energy simulation procedure, there are several energy losses occurring in the individual steps of energy conversion.

3.*7.2* Financial Analysis of hybrid system

Financial Analysis Model for 4 MW AC Solar Plant and Pumped storage Hydropower. This financial analysis compares the revenue, cost, and return on investment (ROI) for the existing 7.5 MW Indrawati III Hydropower and the proposed 4 MW solar-pumped plant based on the given Power Purchase Agreement (PPA) rates.

For 4MW ac solar-PSH plant:

Component	Capacity	Cost(NRS)
For Solar plant		
Solar panels+ mounting	4MWAC	350000000 (Solar, n.d.)
Inverters, cablings,		50000000 (Sungrow, n.d.)
Civil, fenching		15000000
Total CAPEX		45000000
For PHS		
Pumps		200000000 (CWTW, n.d.)
Penstock civil reservoirs		250000000
Valves, gates		500000000 (CWTW, n.d.)
Control, SCADA		30000000 (CWTW, n.d.)
Contingences		60000000
Total		1000000000

Table 5: Financial Assumptions and Parameters for 4 MWac Solar-PSH Plant Design:

Parameter	Solar Plant (4 MW)/PSH
Installed Capacity	
Parameter	Solar Plant (MWac)
Installed Capacity	4970 MW
Annual Energy Generation	8032 GWh

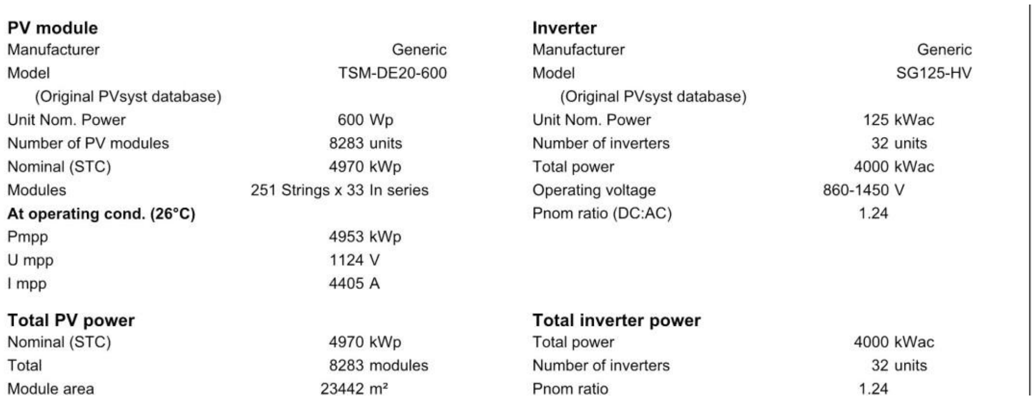
Investment	Loan-45%, Equity- 55%
PPA Rate (NPR/kWh)	8.5 and 12 (Peak hours) (2)
Total Investment Cost (NPR Million)	1000 million (1arba)
O&M Cost (% of Capex/yr)	3%
Project Lifetime	25 years

4. RESULT AND DISCUSSION OF SIMULATION

4.1 Result from PVsyst simulation:

To evaluate the performance of the proposed 4 MWAC solar PV system integrated with the Indrawati Hydropower Plant, a detailed energy simulation was conducted using PVsyst, a widely accepted software tool for photovoltaic system design and performance analysis.

Table 6: Result summary



PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	TSM-DE20-600	Model	SG125-HV
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	600 Wp	Unit Nom. Power	125 kWac
Number of PV modules	8283 units	Number of inverters	32 units
Nominal (STC)	4970 kWp	Total power	4000 kWac
Modules	251 Strings x 33 In series	Operating voltage	860-1450 V
At operating cond. (26°C)		Pnom ratio (DC:AC)	1.24
Pmpp	4953 kWp		
U mpp	1124 V		
I mpp	4405 A		
Total PV power		**Total inverter power**	
Nominal (STC)	4970 kWp	Total power	4000 kWac
Total	8283 modules	Number of inverters	32 units
Module area	23442 m²	Pnom ratio	1.24

Figure 10Array Output

This table provides detailed technical specifications of a photovoltaic (PV) system that includes both PV modules and inverters. Below is an explanation of the different parameters and their meanings:

PV Module:

Manufacturer: The manufacturer is listed as Generic, meaning the brand is not specified or it is a standard or unbranded product.

- Model: The model of the PV module is TSM-NEG19RC-600.
- Unit Nominal Power: Each module has a nominal power of 600 Wp (watts peak), which is the maximum power the module can generate under standard test conditions (STC).
- Number of PV Modules: The system consists of 8283 PV modules in total.
- Nominal Power (STC): The total power generated by the modules under standard test conditions is 4000 kWp.

- Modules Configuration: The modules are arranged in 251 strings, each consisting of 33 modules in series.

Inverter:

- Manufacturer: The inverters are also from a Generic manufacturer.
- Model: The model of the inverter is SG125-HX, which is a commonly used string inverter model.
- Unit Nominal Power: Each inverter has a nominal power of 125 kWac (kilowatts alternating current).
- Number of Inverters: The system uses 32 inverters
- Operating Voltage: The inverters operate in the voltage range of 850-1450 V.

System Design and Performance:

- Nominal Power at Operating Conditions (26°C): The nominal power at operating conditions is slightly adjusted to Pmpp = 7489 kWp.
- Pnom Ratio (DC:AC): The DC to AC power ratio is 1.24, indicating that the system is designed with a slightly oversized DC side (from the modules) compared to the AC side (from the inverters). This is common to ensure that the inverters operate at their maximum efficiency.

- Power Sharing: There is no power sharing between MPPTs, meaning that each MPPT on the inverter operates independently, which could help in optimizing energy generation from different parts of the system, especially if they experience different shading or conditions.

Electrical Parameters:

- U mpp (Voltage at Maximum Power Point): The voltage at the maximum power point is 999 V, which refers to the optimal operating voltage of the system for maximum efficiency.
- I mpp (Current at Maximum Power Point): The current at the maximum power point is 7500 A, which corresponds to the current flowing when the system is producing its peak power.

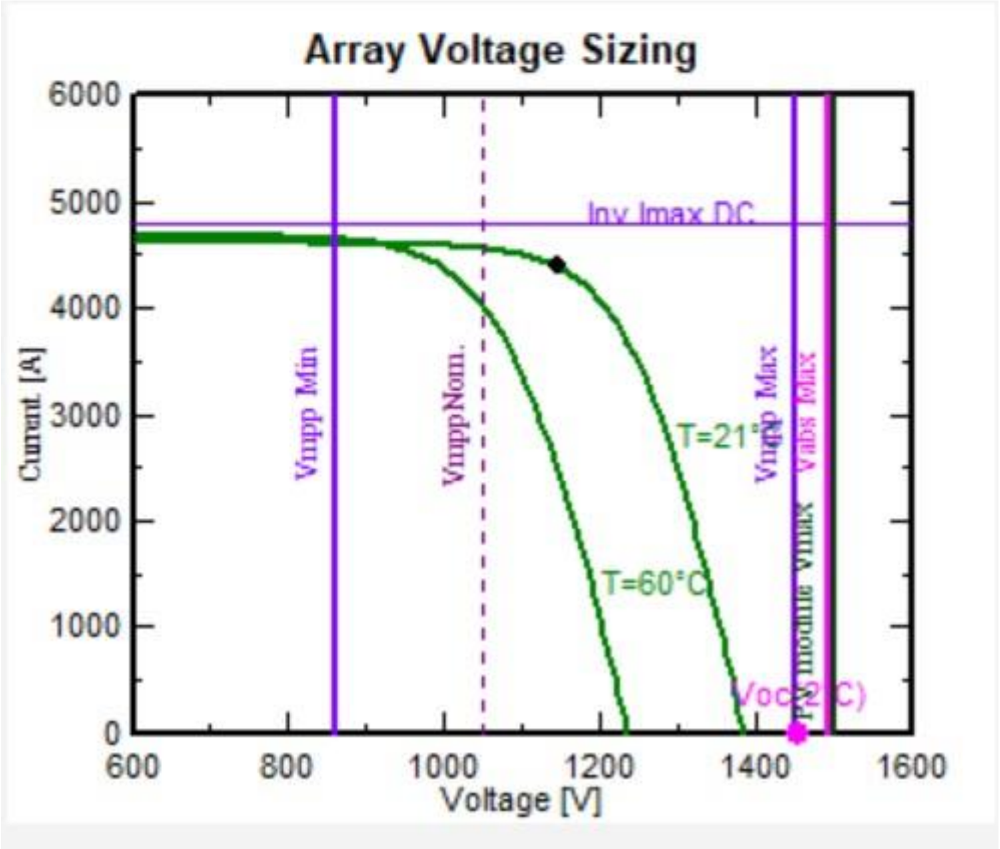


Figure 11 MPPT Curve

This graph illustrates the current–voltage (I-V) characteristics of a solar array under different temperature conditions and is used for proper array voltage sizing in relation to inverter limits. The two green curves represent the I-V behavior of the array at 21°C and 60°C. As temperature increases, the voltage output of the array decreases, while current remains nearly constant.The graph ensures that across temperature variations, the array voltage stays within the MPPT window for efficient tracking, and the open-circuit voltage never exceeds inverter safety limits in cold conditions, while also ensuring that the current does not surpass inverter input capacity.

System Area and Utilization:

- Module Area: The total area occupied by the PV modules is 23442 m², which represents the physical space required for the installation of the panels.

Total Power Generation:

- Total PV Power (Nominal STC): The total nominal power from the PV modules under standard test conditions is 5000 kWp.

- Total Inverter Power: The total nominal power capacity of the inverters is 4000 kWac.

Summary:

- DC to AC Power Ratio (Pnom ratio): The ratio is 1.24. This ensures that the system remains efficient and doesn't underperform due to inverter limitations.
- Inverter Details: The system utilizes 32 inverters, with a total inverter power of 4000 kWac, which is slightly smaller than the total PV system power at 4970 kWp.
- System Configuration: The modules are arranged in 253 strings of 33 modules each, and the design allows for efficient operation at various conditions with the MPPT tracking feature to maximize power generation.

4.2 Normalized Energy production and Performance Ratio

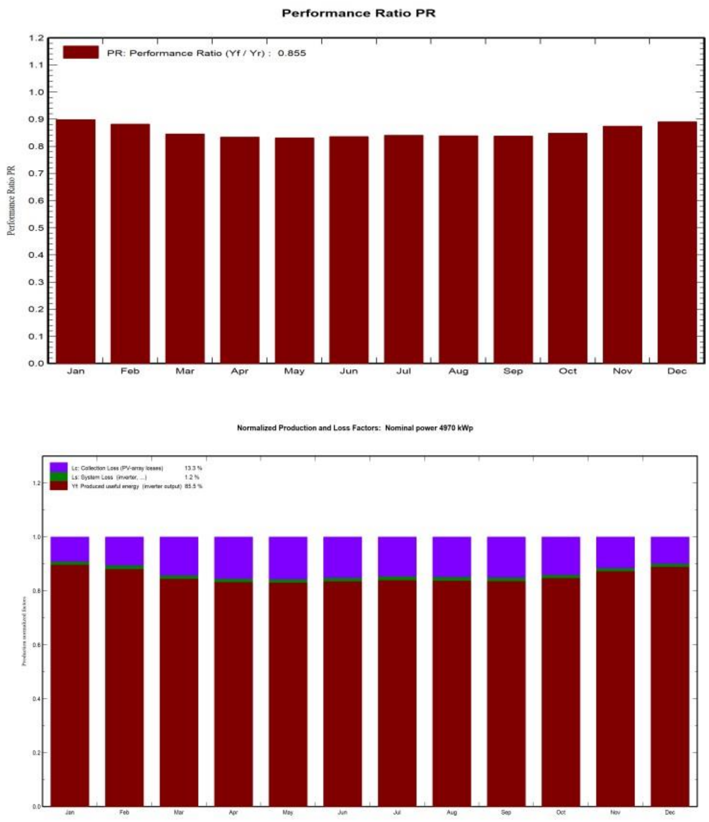


Figure 12 PR and Energy output

The above graph represents the normalized energy output (Yf) and system losses for each month. The brown bars indicate the final energy output from the inverter (Yf in kWh/kWp/day), while the green (system losses, Ls) and purple (collection losses, Lc from PV-array losses) sections represent the losses in the system. The total height of the bars suggests the potential energy generation, but losses reduce the actual usable output. Energy production varies throughout the year, with higher values from March to August, likely due to increased solar irradiance, while losses remain relatively consistent.

This graph shows the Performance Ratio (PR), a key metric indicating system efficiency (Yf/Yr), where Yr is the reference energy from the solar resource. The brown bars represent the PR across different months, with an average value of 0.85 (85%). The PR remains relatively stable throughout the year but shows a slight decline during the monsoon months (July, August) and the winter months (November, December), possibly due to reduced sunlight or increased system losses.

These graphs highlight the seasonal variation in PV system performance. The energy output is higherCXC C in summer**,** correlating with higher solar radiation**,** while performance efficiency (PR) is relatively stable but slightly affected by environmental conditions such as temperature, shading, or dirt accumulation on panels. The losses (Lc and Ls) remain consistent, indicating that the system's inefficiencies are predictable and manageable.

4.3 P50 - P90 evaluation

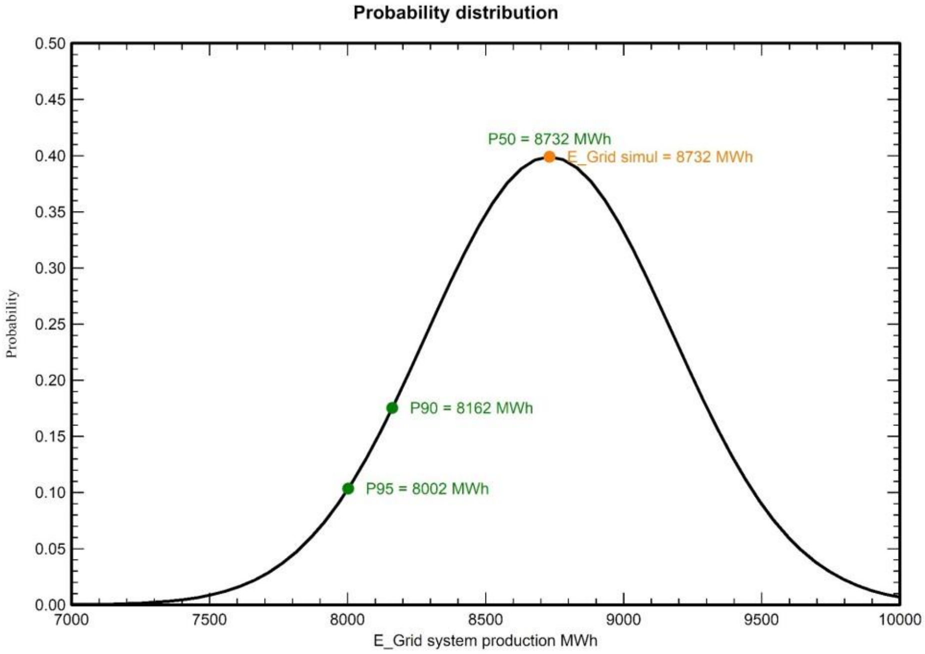


Figure 13: P50-P90 evaluation

This graph represents a normal distribution of E_Grid system production (MWh), showing the probability distribution of expected energy generation from the solar plant. The key statistical indicators in the graph include:

- P50 (8732 MWh): The median or expected energy production value, indicating that there is a 50% probability of generating at least this amount.
- P90 (8162MWh): Represents a conservative estimate where there is a 90% probability of achieving at least this level of energy generation.
- P95 (8002 MWh): A more risk-averse estimate, ensuring a 95% probability that energy generation will not fall below this value.

The distribution suggests that most probable energy generation falls around the P50 value, with a decreasing probability of exceeding or underperforming significantly. The left tail (lower production) represents the risk of lower-than-expected output due to soiling, mismatches, weather variability, or other system inefficiencies. The right tail represents potential but less likely scenarios of higher generation.

4.4 Monthly Energy Production

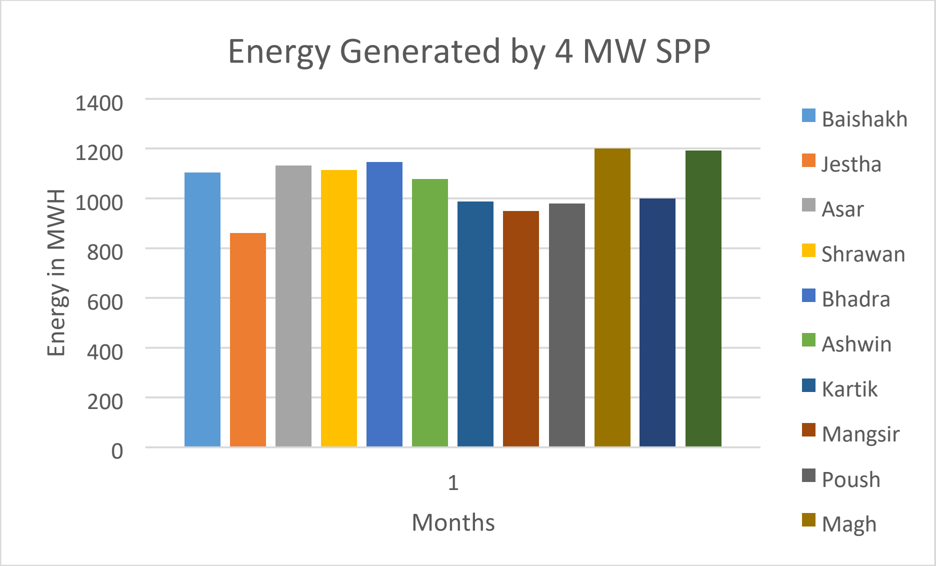


Figure 14: Energy generated by 4 MW SPP

This bar chart represents the monthly energy generation of a 4 MW Small Power Plant (SPP) in megawatt-hours (MWh) over different months. Magh and Poush months appear to have the highest energy generation, reaching around MWh**.** Jestha seems to have the lowest energy generation, below 1000 MWh**.** The months with higher energy generation (Magh, Asar) is experiencing favorable hydrological conditions. The months with lower energy generation (Jestha, Kartik) is affected by low water availability**,** maintenance schedules**,** or reduced efficiency due to seasonal changes**.**

This figure provides insight into the seasonal energy generation trends of the 4 MW Power Plant (SPP)**,** which is hydropower-based given the fluctuations in energy production. The chart can be useful for hydropower operation planning, maintenance scheduling, and understanding seasonal variability in power generation**.**

4.5Hourly generation from combined Solar-PSH with Indrawati III Hydropower

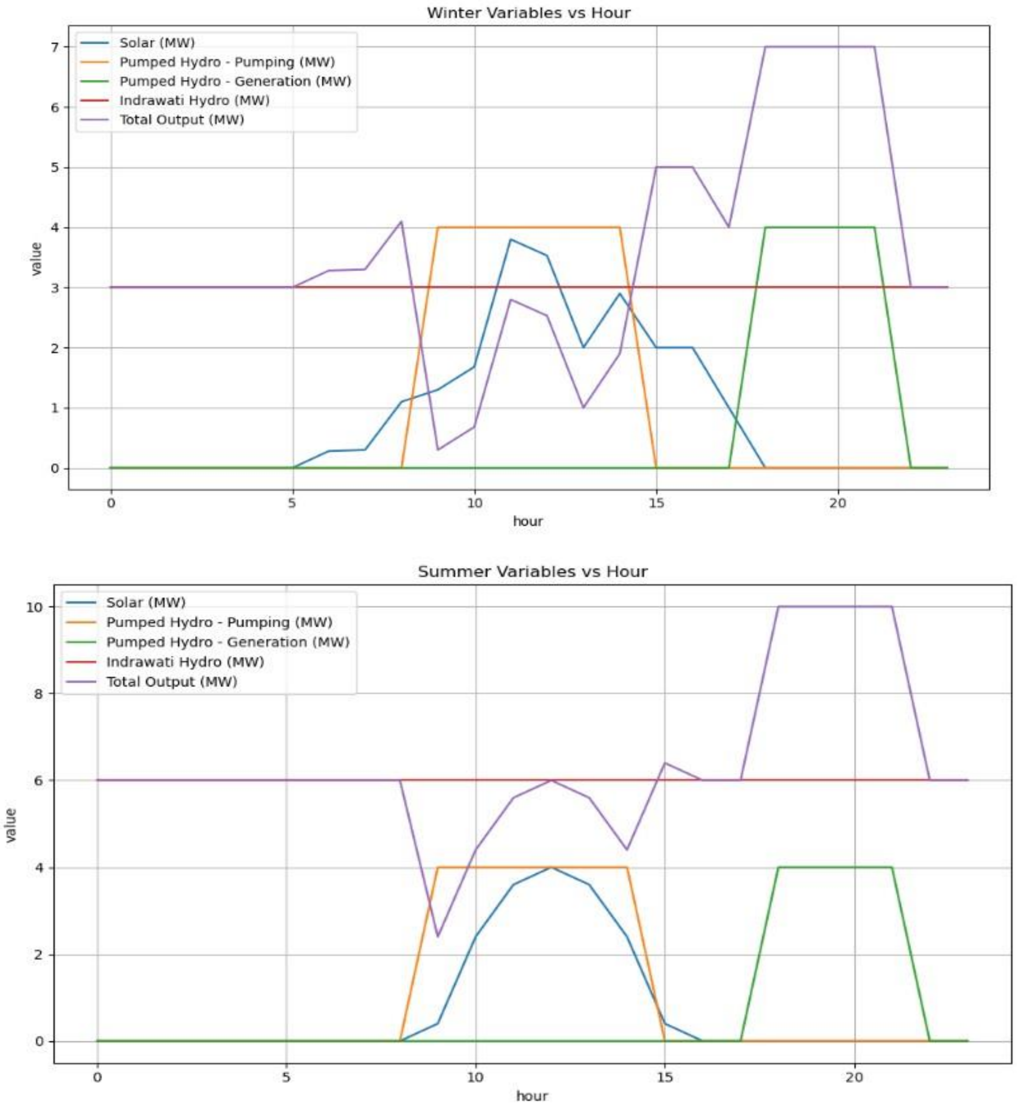


Figure 15 Daily Combined energy generation

The blue line indicates solar output, which increases during daylight hours before declining in the evening. The orange and green lines represent Pumped Hydro—pumping occurs during specific hours, while generation peaks later in the day, likely balancing energy needs during reduced solar activity. Indrawati III Hydro, shown as a red line, remains constant at 3 MW throughout the day, providing steady support. The purple line illustrates Total Output, showing fluctuations as it incorporates contributions from all sources. This graph effectively demonstrates the dynamics of energy resource utilization and management during winter hours, ensuring a sustainable supply throughout the day

In summer the graph showcases the fluctuations in energy generation and output over a 24-hour period. The x-axis represents the time in hours, ranging from 0 to 24, while the y-axis displays the energy values measured in megawatts (MW). It highlights five key components: Solar energy, Pumped Hydro (both pumping and generation), Indrawati Hydro, and the Total Output. Solar energy peaks midday, around hours 10–15, aligning with optimal sunlight conditions. Pumped Hydro exhibits an interplay between pumping (active during midday) and generation (predominantly from hours 15–20), reflecting efforts to balance energy availability during reduced solar activity. Indrawati Hydro maintains consistent output throughout the day with minor fluctuations, ensuring stability. Meanwhile, the Total Output remains steady at approximately 6 MW, showcasing an effective energy management strategy to meet demands despite variances in generation sources. This graph effectively illustrates the dynamic coordination of energy resources to achieve a balanced and sustainable supply during summer hours.

4.5 Combined energy production from hybrid system

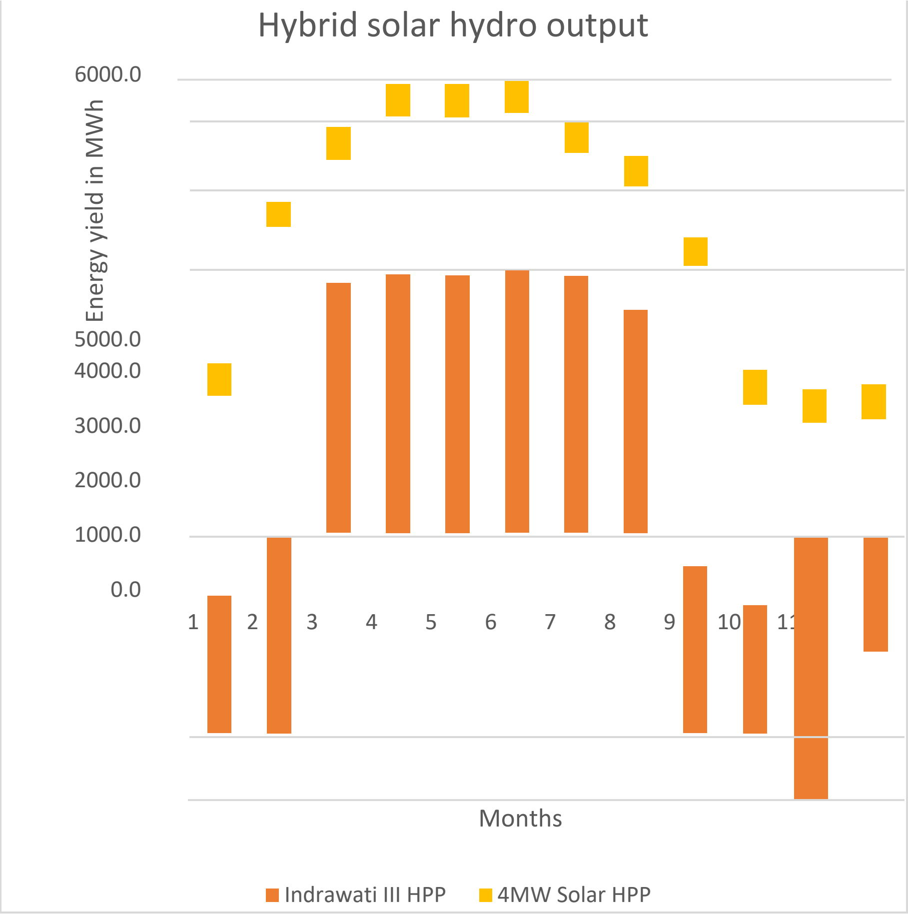


Figure 13: Hybrid model

This bar chart represents energy generation from a Hybrid Model consisting of hydropower (Hydro) and solar power (Solar) over 12 months. The blue bars (Hydro) are significantly larger than the orange bars (Solar), indicating that hydropower is the primary source of energy in this hybrid model. The highest hydro energy production occurs from April to August (months 4 to 8), reaching nearly 5000–5500 MWh.

Hydro production decreases in the later months, with the lowest values observed in November and December (months 10–12). The orange bars (Solar) remain relatively stable across all months, producing a small but consistent amount of energy. This suggests that solar power is less affected by seasonal variations compared to hydropower. The peak in hydro production occurs during the monsoon months (May to August) when water availability is high. The decline in hydro production from September to February is due to reduced river flow during the dry season.

This hybrid energy model effectively combines hydropower and solar power, leveraging seasonal variations. Hydro power is dominant but fluctuates with seasonal water availability, while solar provides a stable but smaller contribution.

4.6 Economic Analysis of hybrid plant

Table 7: Average Revenue from solar- hydro PP

Plant	Energy (GWh)	PPA Rate (NPR/kWh)	Annual Revenue (Million NPR)
Hydropower	49592GWh	4.83	19.5 crore
Solar Plant	8858.074 GWh	8.5	4 crore

Plant	Energy (GWh)	PPA Rate (NPR/kWh)	Annual Revenue (Million NPR)
Solar and pumped storage hydro	8099.507	12 peak hour & 8.5 wet season	1200000

Comparison of Solar integrated system with solar-pumped storage hydropower in an existing hydropower:

Parameters	Solar Integrated system	Solar-Pumped storage system
IRR	14.14%	8.56%
NPV	17177993	5816363

ROE	29.6%	16.32%
Payback period	5 years	7years

The table compares key financial indicators for two types of solar-based energy systems: a Solar Integrated System and a Solar-Pumped Storage System. The Solar Integrated System demonstrates stronger financial performance across all metrics. It has an Internal Rate of Return (IRR) of 14.14%, significantly higher than the 8.56% for the pumped storage variant, indicating better profitability. The Net Present Value (NPV) is also higher at NPR 17.18 million compared to NPR 5.82 million, suggesting greater long-term value generation. Additionally, the Return on Equity (ROE) for the Solar Integrated System stands at 29.6%, nearly double that of the Solar-Pumped Storage System (16.32%), reflecting more efficient use of investor capital. Lastly, the is shorter at 5 years versus 7 years, meaning investors recover their initial investment more quickly in the integrated system. Overall, while both systems are financially viable, the Solar Integrated System offers superior returns and a faster investment recovery.

4.7 Load Flow Analysis for power evacuation to INPS

The study was conducted to analyze the steady-state performance of the integrated system under various operational scenarios. Given the dynamic nature of renewable energy sources, particularly solar, and the strategic role of pumped storage in balancing generation and demand, a detailed power flow analysis was required to ensure system reliability and efficiency.

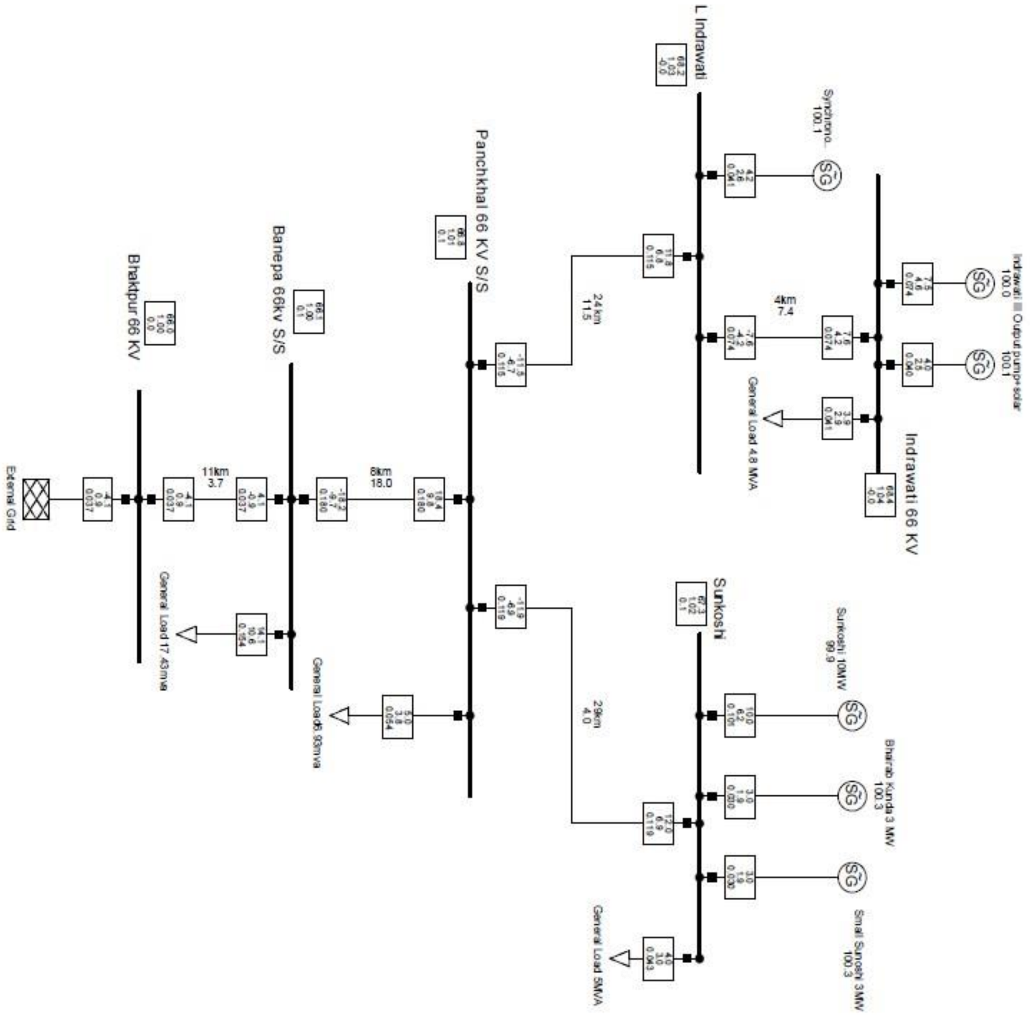


Figure 16 Load Flow Analysis

Based on the load flow analysis performed using DIgSILENT Power Factory, the integrated system consisting of the 7.5 MW Indrawati III Hydropower Plant, the 4 MW hybrid solar and pumped hydro system, and associated generators (Sunkoshi, Bhairab Kunda, and Small Sunkoshi) is operating in a stable condition. The voltage profile across all substations — including Bhaktapur, Banepa, Panchkhal, Sunkoshi, L-Indrawati, and Indrawati 66 kV remains well within acceptable limits, ranging from 1.00 to 1.04 per unit, indicating strong voltage regulation and no signs of undervoltage or overvoltage issues in the network.

The hybrid system comprising the 4 MW solar and pumped hydro unit is actively injecting 4 MW of active power and 2.5 MVAr of reactive power into the grid, with a current loading of 0.040 kA, which is moderate and shows no sign of line overloading. The existing Indrawati III Plant contributes 7.5 MW and 4.6 MVAr, while nearby generators such as Sunkoshi (10 MW) and Bhairab Kunda (3 MW) are contributing as expected, confirming balanced generation across the network. Several general load centers have been modeled, including a 17.43 MVA load block (14.1 MW real power), 6.93 MVA, 5 MVA, and 4.8 MVA, which collectively represent a substantial portion of the demand.

In terms of line loading, the analysis shows no signs of overloading. For instance, a 29 km transmission line is transferring 12 MW active and 6.9 MVAr reactive power in one direction, with a return flow of -11.9 MW and -6.9 MVAr, and a current magnitude of 0.119 kA. Similarly, another line of 24 km length shows 11.8 MW flow with 6.8 MVAr, and a line current of 0.115 kA, all of which are within normal thermal and capacity limits. These values suggest that the transmission system is welldesigned to accommodate both generation and load, with no significant bottlenecks or congestions observed under current operating conditions.

Overall, the load flow analysis confirms the technical viability of the solar + pumped hydro integration with the existing 7.5 MW Indrawati plant. The system demonstrates good voltage stability, balanced generation and load, and healthy line loading—making it a strong candidate for hybrid operation in both wet and dry seasons.

5. CONCLUSIONS AND RECOMMENDATION

The study highlights the critical challenges faced by Nepal’s hydropower sector due to seasonal fluctuations in river discharge. Given the country’s increasing energy demand, integrating solar power with existing hydropower infrastructure presents a viable solution to mitigate energy shortages. The analysis reveals that hybrid power plants can enhance energy stability, reduce reliance on imports, and promote a more sustainable energy mix. However, successful implementation requires strategic investment, supportive government policies, and advancements in energy storage and grid integration technologies. Future research should focus on optimizing hybrid system configurations and assessing long-term economic benefits. By adopting a hybrid energy approach, Nepal can move towards a more resilient and self-sufficient power sector, ensuring sustainable energy security for future generations. The conclusion of the report is described below

- The historical generation data of Indrawati III Hydropower was analysed to identify seasonal shortages.
- 4 MW grid-connected solar system using PVSYST simulation was desigend.
- Solar-hydro complementarity for stable power output and analyze its financial feasibility.

Based on the study’s conclusions, it is recommended that both the Government of Nepal and the Nepal Electricity Authority (NEA) take strategic actions to accelerate the deployment of hybrid solar-hydro systems with an emphasis on integrating pumped storage hydro. The Government of Nepal should first establish a comprehensive policy framework that promotes hybrid energy systems, explicitly incorporating pumped hydro as a viable and scalable storage solution. Financial incentives such as tax relief, low-interest green loans, and viability gap funding should be introduced to attract private investment in solar, hydropower, and storage infrastructure. Moreover, the government should prioritize investments in national grid infrastructure upgrades to support the variable nature of renewables and ensure reliable integration. To reduce import dependency and boost local employment, incentives should also support domestic manufacturing and innovation in solar technology and hydro-mechanical equipment. Importantly, pumped hydro should be included in national energy planning as a long-duration energy storage option to shift surplus energy from solar during the day to meet peak demands in the evening and during dry seasons.

For NEA, it is vital to identify existing hydropower plants—such as the Indrawati III Hydropower Station—that are suitable for integration with solar PV and pumped hydro systems. Conducting feasibility studies and developing pilot projects that combine solar energy with pumped storage will be instrumental in demonstrating the technical and financial viability of such hybrid systems. NEA should also modernize its grid operations by adopting smart grid technologies, load forecasting tools, and seasonal dispatch strategies to manage intermittent solar energy and storage discharge effectively. In addition, the authority should foster collaboration with academic institutions and international partners to enhance research and development on hybrid energy optimization, storage sizing, and grid integration. Building technical capacity through training programs will ensure smooth operation and long-term sustainability. By implementing these measures, Nepal can establish a robust and flexible power system that leverages solar energy, conventional hydropower, and pumped hydro storage—ensuring year-round energy security and a sustainable transition toward a clean energy future.

6. REFERENCES

EMBER,https://ember-energy.org/tr/analizler/hibrit-santraller-ile-gunes-kapasitesiruzgari-geride-birakti/,Yıldırım, A., Access Date: February 22, 2024.

NEA Annual Report 2081.

Mohammadi, S. A. D., Gezegin, C., 2022. Design and simulation of grid-connected solar PV system using PVsyst, PVGIS and HOMER software, Int. J. Pioneering Technol. Eng., 1[2],pp. 36-41.

Agyekum, E. B. (2022). A 3E, hydrogen production, irrigation, and employment potential assessment of a hybrid energy system for tropical weather conditions - Combination of HOMER software, shannon entropy, and TOPSIS,. 47: Int. J. Hydrogen Energy.

Anandhi, R. J. (2024). Hybrid solar-hydropower system for green energy production: a comprehensive analysi.

Balan, M. H. (2023). Hydro-solar hybrid plant operation in a hydropower plant cascade: optimizing local and bulk system benefits, Wate.

Campos, E. F. (2021). Hybrid power generation for increasing water and energy securities during drought: Exploring local and regional effects in a semi-arid basin. . Environ. Manag., .

Cazzaniga, R. R.-C.-C. (2019). Integration of PV floating with hydroelectric power plants.

Dursun, M. S. (2023). Reservoir effect on the hybrid solar-hydroelectric (She) System. J. Polytech.

EMBER, h.-e.-s.-i.-g.-k.-r.-g.-b. A. (n.d.).

EMBER,https://ember-energy.org/tr/analizler/hibrit-santraller-ile-gunes-kapasitesiruzgari-geride-birakti/,Yıldırım, A., Access Date: February 22, 2024. (n.d.).

Gupta, M. (2024, ferbruary). Integration Of Solar And Pumped Hydro Storage: A Technical Overview. Retrieved from solarquarter.com.

IRENA. (n.d.). 2020.

Mehadi, A. A. (2021). Optimized seasonal performance analysis and integrated operation of 50 MW floating solar photovoltaic system with Kaptai hydroelectric power plant: a case study.Energy Sources Part A: Recovery Util. Environ. Effects.

Muhammad Shahzad Javed, T. M. (2020). Solar and wind power generation systems with pumped hydro storage: Review and future perspectives. Elsevier, 176-192.

Olkkonen, V. H. (2023). Techno-economic feasibility of hybrid hydro-FPV systems in Sub- Saharan Africa under different market conditions, Renew. Energy, 215 (2023), pp. 118981.

Pianco, F. M. (2022). Hydroelectric operation for hybridization with a floating photovoltaic plant: A case of study, Renew. Energy. 85-95.

Rodriguez, L. (2023). Potential for solar PV to enhance hydropower plants.

Agarkar, Bhushan D., and Shivprakash B. Barve. "A Review on Hybrid solar/wind/hydro power generation system." International Journal of Current Engineering and Technology 4, no. 4 (2016): 188-191.

Raghu, M. S., Kumar, C. P., Prashanth, M. K., Kumar, K. Y., Prathibha, B. S., Kanthimathi, G., ... & Osman, S. M. (2021). Novel 1, 3, 5-triazine-based pyrazole derivatives as potential antitumor agents and EFGR kinase inhibitors: Synthesis, cytotoxicity, DNA binding, molecular docking and DFT studies. New Journal of Chemistry, 45(31), 13909-13924.

Awasthi, A., Saxena, K. K., & Arun, V. (2021). Sustainable and smart metal forming manufacturing process. Materials Today: Proceedings, 44, 2069-2079.

Ram, J. P., Pillai, D. S., Ghias, A. M., & Rajasekar, N. (2020). Performance enhancement of solar PV systems applying P&O assisted Flower Pollination Algorithm (FPA). Solar Energy, 199, 214-229.

Kumar, K. Y., Saini, H., Pandiarajan, D., Prashanth, M. K., Parashuram, L., & Raghu,

M. S. (2020). Controllable synthesis of TiO2 chemically bonded graphene for photocatalytic hydrogen evolution and dye degradation. Catalysis Today, 340, 170177.

Manusov, Vadim, Svetlana Beryozkina, Muso Nazarov, Murodbek Safaraliev, Inga Zicmane, Pavel Matrenin, and Anvari Ghulomzoda. "Optimal management of energy consumption in an autonomous power system considering alternative energy sources." Mathematics 10, no. 3 (2022): 525.

Vandana, C. P., & Chikkamannur, A. A. (2021). Feature selection: An empirical study. International Journal of Engineering Trends and Technology, 69(2), 165-170.

Prakash, S., Somiya, G., Elavarasan, N., Subashini, K., Kanaga, S., Dhandapani, R., & Sujatha, V. (2021). Synthesis and characterization of novel bioactive azo compounds fused with benzothiazole and their versatile biological applications. Journal of Molecular Structure, 1224, 129016.

ANNEX

Version 7.4.2

PVsyst - Simulation report

Grid-Connected System

Project: Solar-Indrawati III

Variant: New simulation variant
No 3D scene defined, no shadings
System power: 4970 kWp
Melamchi - Nepal

Author

Project summary

Geographical Site

Melamchi

Nepal

Situation

Latitude	27.87 °N
Longitude	85.60 °E
Altitude	862 m
Time zone	UTC+5.8

Project settings

Albedo	0.20

Meteo data

Melamchi

Meteonorm 8.1 (2016-2021), Sat=100% - Synthetic

System summary

Grid-Connected System

No 3D scene defined, no shadings

PV Field Orientation

Fixed plane

Tilt/Azimuth	20 / 0 °

Near Shadings

No Shadings

User's needs

Unlimited load (grid)

System information

PV Array

Nb. of modules	8283 units
Pnom total	4970 kWp

Inverters

Nb. of units	32 units
Pnom total	4000 kWac
Pnom ratio	1.242

Results summary

Produced Energy	8732055 kWh/year	Specific production	1757 kWh/kWp/year	Perf. Ratio PR	85.47 %

Table of contents

General parameters

Grid-Connected System

No 3D scene defined, no shadings

PV Field Orientation

Orientation

Fixed plane	
Tilt/Azimuth	20 / 0 °

Sheds configuration

No 3D scene defined

Models used

Transposition	Perez
Diffuse	Perez, Meteonorm
Circumsolar	separate

Horizon

Free Horizon

Near Shadings

No Shadings

User's needs

Unlimited load (grid)

PV Array Characteristics

PV module

Manufacturer	Generic
Model	TSM-DE20-600
(Original PVsyst database)	
Unit Nom. Power	600 Wp
Number of PV modules	8283 units
Nominal (STC)	4970 kWp
Modules	251 Strings x 33 In series
At operating cond. (26°C)	
Pmpp	4953 kWp
U mpp	1124 V
I mpp	4405 A

Inverter

Manufacturer	Generic
Model	SG125-HV
(Original PVsyst database)	
Unit Nom. Power	125 kWac
Number of inverters	32 units
Total power	4000 kWac
Operating voltage	860-1450 V
Pnom ratio (DC:AC)	1.24

Total PV power

Nominal (STC)	4970 kWp
Total	8283 modules
Module area	23442 m²

Total inverter power

Total power	4000 kWac
Number of inverters	32 units
Pnom ratio	1.24

Array losses

Thermal Loss factor

Module temperature according to irradiance

Uc (const)	20.0 W/m²K
Uv (wind)	0.0 W/m²K/m/s

DC wiring losses

Global array res.	3.8 mΩ
Loss Fraction	1.5 % at STC

Module Quality Loss

Loss Fraction	-0.7 %

Module mismatch losses

Loss Fraction	2.0 % at MPP

Strings Mismatch loss

Loss Fraction	0.1 %

IAM loss factor

Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

Spectral correction

FirstSolar model

Precipitable water estimated from relative humidity

Coefficient Set	C0	C1	C2	C3	C4	C5
Monocrystalline Si	0.85914	-0.02088	-0.0058853	0.12029	0.026814	-0.001781

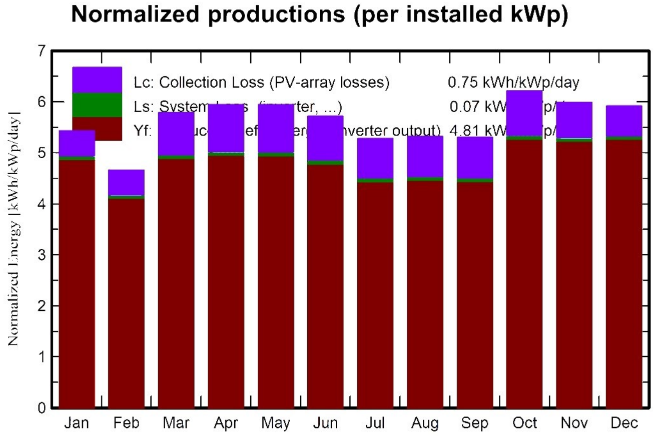
Main results

System Production

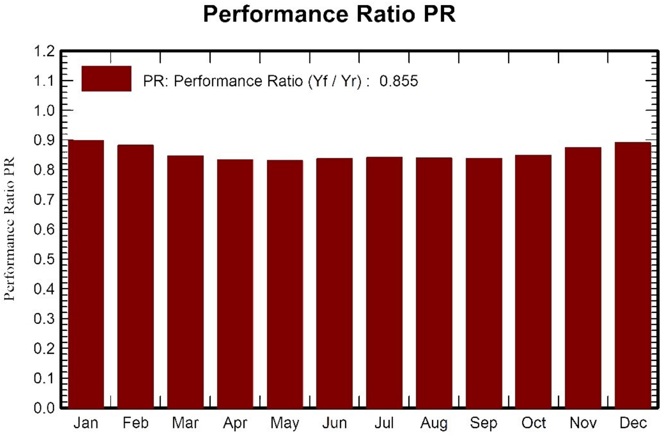
Produced Energy	8732055 kWh/year	Specific production	1757 kWh/kWp/year
		Perf. Ratio PR	85.47 %

Economic evaluation

Investment		**Yearly cost**		**LCOE**	
Global	717687500.00 NEP	Annuities	0.00 NEP/yr	Energy cost	4.14 NEP/kWh
Specific	144 NEP/Wp	Run. costs	258333.00 NEP/yr		
		Payback period	Unprofitable		



Normalized productions (per installed kWp)



Performance Ratio PR

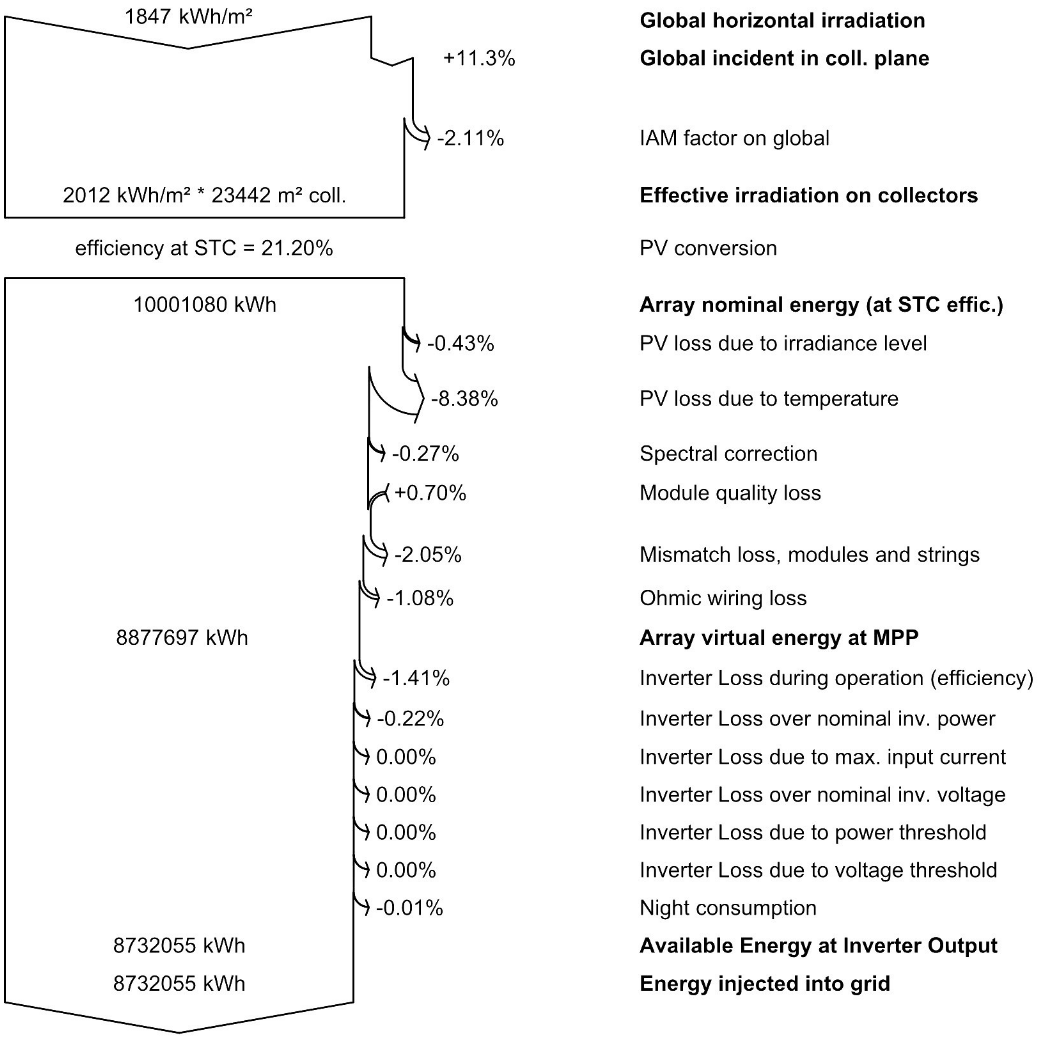
Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio
January	124.0	33.42	10.39	168.4	165.0	761468	751710	0.898
February	109.7	53.05	15.24	130.6	128.0	581121	572508	0.882
March	160.3	65.26	21.08	179.4	175.8	765202	754365	0.846
April	173.4	82.99	25.75	178.3	174.4	749519	738953	0.834
May	189.1	89.47	27.43	184.3	180.1	773127	761667	0.832
June	180.1	91.84	27.18	171.6	167.6	724736	713368	0.837
July	171.1	84.90	25.80	163.6	159.5	694752	683596	0.841
August	165.3	75.86	25.72	165.0	161.0	699057	688200	0.839
September	148.4	62.68	24.77	159.2	155.3	672899	662584	0.838
October	161.6	47.97	22.55	192.6	189.4	823459	812564	0.849
November	134.7	29.30	17.38	179.6	176.4	790577	780632	0.874
December	129.1	23.94	12.16	183.5	179.8	822158	811907	0.891
Year	1846.7	740.68	21.31	2055.8	2012.5	8858074	8732055	0.855

Legends

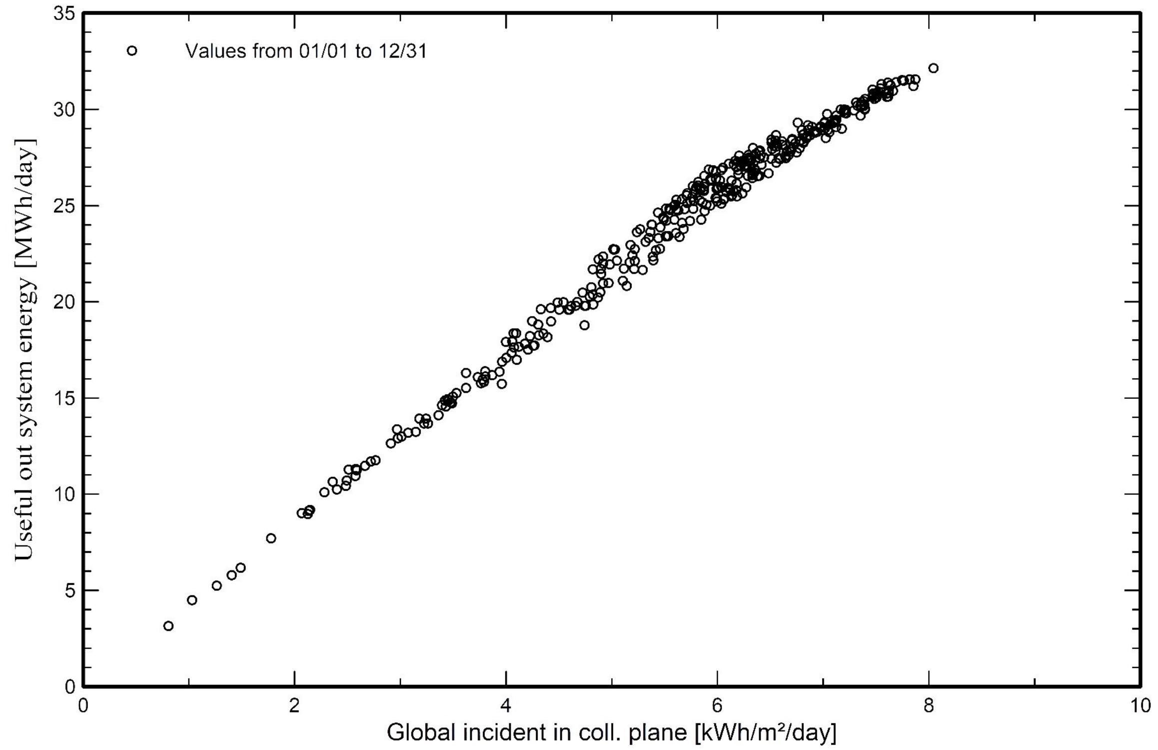
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

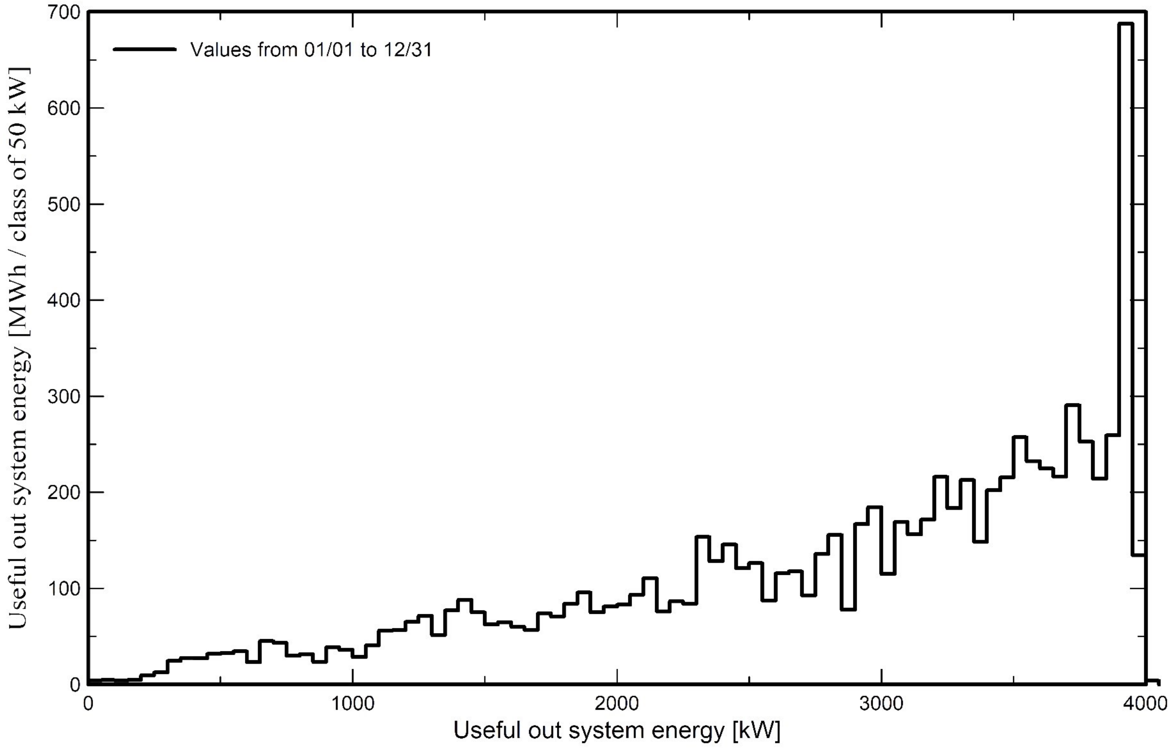


Predef. graphs

Daily Input/Output diagram



System Output Power Distribution



P50 - P90 evaluation

Meteo data

Source	Meteonorm 8.1 (2016-2021), Sat=100%
Kind	Monthly averages
Synthetic - Multi-year average	
Year-to-year variability(Variance)	4.8 %

Specified Deviation

Climate change	0.0 %

Global variability (meteo + system)

Variability (Quadratic sum)	5.1 %

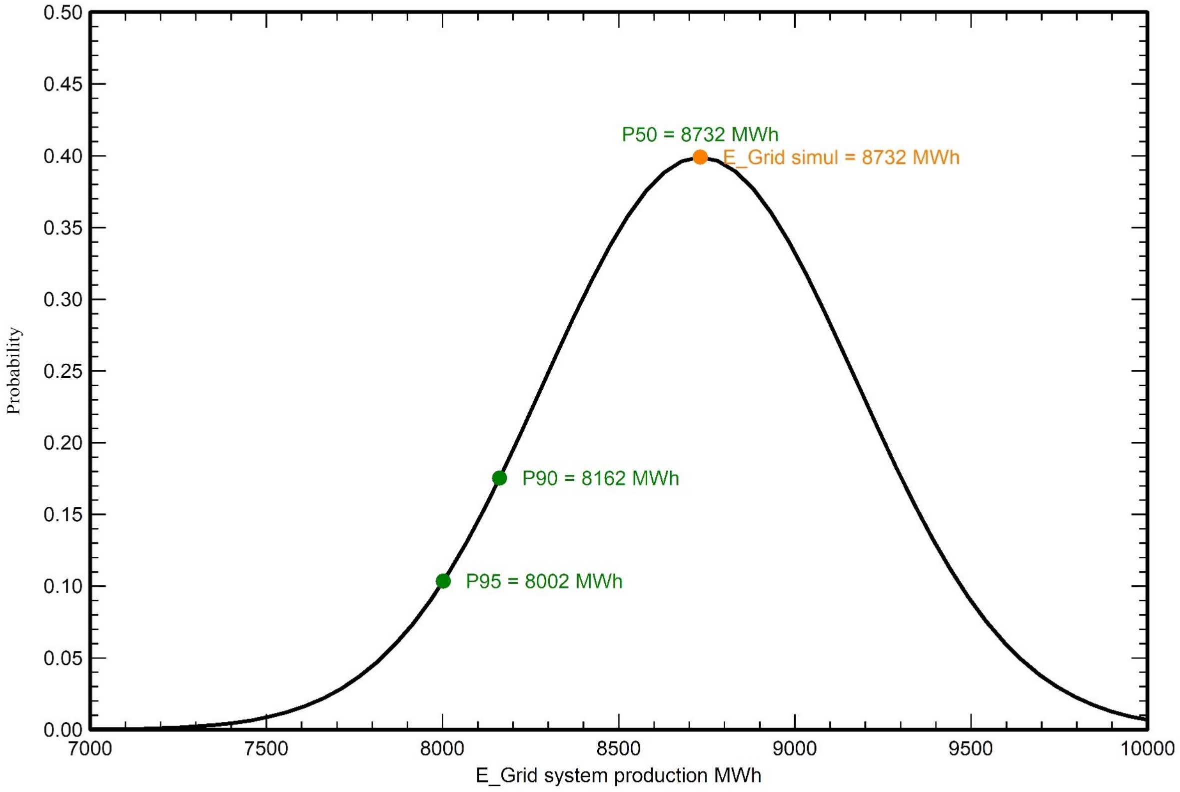
Simulation and parameters uncertainties

PV module modelling/parameters	1.0 %
Inverter efficiency uncertainty	0.5 %
Soiling and mismatch uncertainties	1.0 %
Degradation uncertainty	1.0 %

Annual production probability

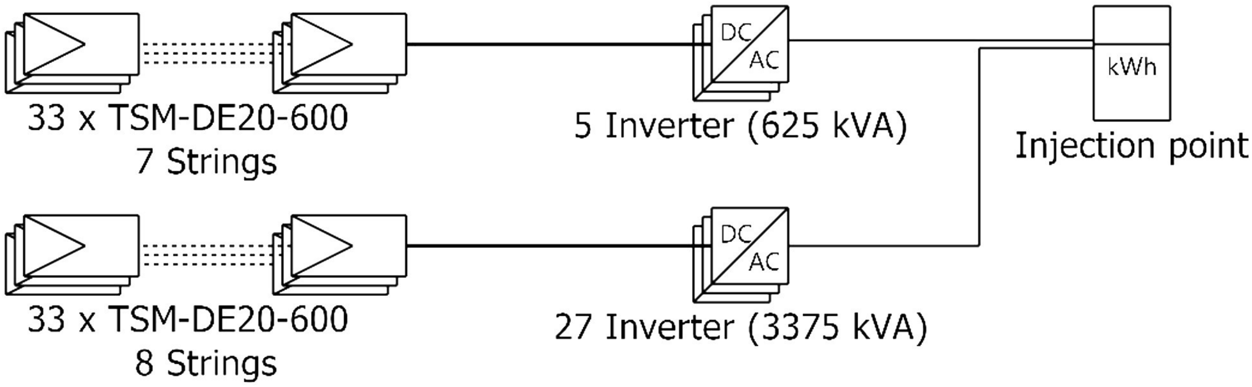
Variability	444 MWh
P50	8732 MWh
P90	8162 MWh
P95	8002 MWh

Probability distribution



PVsyst V7.4.2
VC0, Simulation date:
04/12/25 08:01
with v7.4.2

Single-line diagram



PV module	TSM-DE20-600
Inverter	SG125-HV
String	33 x TSM-DE20-600

Solar-Indrawati III

VC0 : New simulation variant

04/12/25

Cost of the system

Installation costs

Item	Quantity units	Cost NEP	Total NEP
PV modules			
TSM-DE20-600	8283	50000.00	414150000.00
Supports for modules	8283	12500.00	103537500.00
Studies and analysis			
Engineering	1	200000000.00	200000000.00
		Total	717687500.00
		Depreciable asset	517687500.00

Operating costs

Item	Total NEP/year
Maintenance	
Repairs	258333.00
Total (OPEX)	258333.00

System summary

Total installation cost	717687500.00 NEP
Operating costs	258333.00 NEP/year
Produced Energy	8733 MWh/year
Cost of produced energy (LCOE)	4.139 NEP/kWh

CO_2 Emission Balance

Total:	-7832.7 tCO_2

Generated emissions

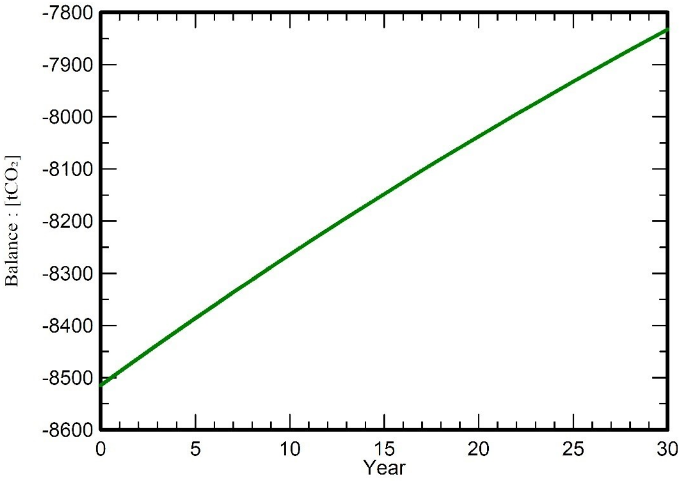
Total:	8514.57 tCO_2

Source: Detailed calculation from table below

Replaced Emissions

Total:	785.9 tCO_2
System production:	8732.06 MWh/yr
Grid Lifecycle Emissions:	3 gCO_2/kWh
Source:	IEA List
Country:	Nepal
Lifetime:	30 years
Annual degradation:	1.0 %

Saved CO_2 Emission vs. Time



System Lifecycle Emissions Details

Item	LCE	Quantity	Subtotal
			[$kgCO_2$]
Modules	1713 kgCO2/kWp	4970 kWp	8512903
Supports	0.02 kgCO2/kg	82840 kg	1658
Inverters	1.98 kgCO2/	4.00	7.93

Lower Erkhuwa HP Project			ROE	FIRR	NPV					
Plant capacity (kW)	4,000		16.2%	8.56%	5,816,363					
						Energy rate		escalation		Financail outlay
O&M Cost (% of investment)	0.35%	of capital cost				**dry peak**	**12.00**	0.36	**Rs./kWh**	Year 1
		Loan A	Equity	**140**	**Rs**	**dry off peak**	**0.00**	0.000	**Rs./kWh**	Year 2
Debt: Equity		40%	60%	**9**		**wet**	**8.40**	0.252	**Rs./kWh**	
Total investment (Rs):	1,000,000,000	400,000,000	600,000,000	3%	p.a.	**escalation**	**3%**		**nine times**	
Depreciation	4%	linear over 25 yrs				Energy generation				
Interest rate loan A	10.00%					Dry season peak	4,006,677	kWh		
Loan term for Loan A	12	years				Dry season off peak	-	kWh		
Insurance (of total investment)	0.35%					wet season	4,092,830	kWh		
							8,099,507			
		2025	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
year		**1**	**2**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
				1	2	3	4	5	6	7
Dry season peak				12.000	12.360	12.720	13.080	13.440	13.800	14.160
Dry energy rate off peak (NRs)				0.000	0.000	0.000	0.000	0.000	0.000	0.000
wet energy rate (NRs)				8.400	8.652	8.904	9.156	9.408	9.660	9.912
Revenue:										
Total revenue in NRS		(200,000,000)	(300,000,000)	82,459,896	84,933,693	87,407,490	89,881,287	92,355,084	94,828,880	97,302,677
operational expenses										
Operation/maint... Cost (NRS)				3,500,000	3,605,000	3,713,150	3,824,545	3,939,281	4,057,459	4,179,183
Insurance				3,500,000	3,605,000	3,713,150	3,824,545	3,939,281	4,057,459	4,179,183
Operating Revenue		(200,000,000)	(300,000,000)	75,459,896	77,723,693	79,981,190	82,232,198	84,476,522	86,713,962	88,944,311
Depreciation				40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000
EBIT		**(200,000,000)**	**(300,000,000)**	**35,459,896**	**37,723,693**	**39,981,190**	**42,232,198**	**44,476,522**	**46,713,962**	**48,944,311**
Project IRR	8.56%									
Interest loan A	10.0%			40,000,000	38,400,000	36,600,000	34,600,000	32,400,000	30,000,000	27,400,000
EBT				**(4,540,104)**	**(676,307)**	**3,381,190**	**7,632,198**	**12,076,522**	**16,713,962**	**21,544,311**
Tax & Royalty										
Royalty (energy)	2%			1,649,198	1,698,674	1,748,150	1,797,626	1,847,102	1,896,578	1,946,054
Royalty (energy)	10%									
Royalty(capacity) $/kW	100			400,000	400,000	400,000	400,000	400,000	400,000	400,000
Royalty(capacity) $/kW	1000									
Total royalty				2,049,198	2,098,674	2,148,150	2,197,626	2,247,102	2,296,578	2,346,054
tax (after 7th year)										
1-7 years	0%			-	-	-	-	-	-	-
8-10 years	10%			-	-	-	-	-	-	-
<10 years	20%									
total tax				-	-	-	-	-	-	-
Net Profit				(6,589,302)	(2,774,981)	1,233,040	5,434,572	9,829,420	14,417,384	19,198,258
Net cash flow before principal payment				33,410,698	37,225,019	41,233,040	45,434,572	49,829,420	54,417,384	59,198,258
Principal repayment %	100%			4.00%	4.50%	5.00%	5.50%	6.00%	6.50%	7.50%
principal payment on loan	400,000,000			16,000,000	18,000,000	20,000,000	22,000,000	24,000,000	26,000,000	30,000,000
Cash flow after interest and principal repayment				17,410,698	19,225,019	21,233,040	23,434,572	25,829,420	28,417,384	29,198,258
Project cash flow		(200,000,000)	(300,000,000)	33,410,698	37,225,019	41,233,040	45,434,572	49,829,420	54,417,384	59,198,258
Nep present value (NPV)	**5,816,363**									
DSCR average/ minimu	**1.45**	**1.35**		1.35	1.38	1.41	1.45	1.50	1.55	1.55
Cash flow to equity	(300,000,000)	(120,000,000)	(180,000,000)	17,410,698	19,225,019	21,233,040	23,434,572	25,829,420	28,417,384	29,198,258
Return on investment	16.2%									
NPV of equity	($14,755,461.87)									
Cost ($) per kW	**1,786**									

	loan	equity	total
20%	80,000,000	120,000,000	200,000,000
30%	120,000,000	180,000,000	300,000,000
			500,000,000

2034	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**
9	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
8	9	10	11	12	13	14	15	16	17	18	19
14.520	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.164	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416
99,776,474	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271
4,304,559	4,433,695	4,566,706	4,703,707	4,844,819	4,990,163	5,139,868	5,294,064	5,452,886	5,616,473	5,784,967	5,958,516
4,304,559	4,433,695	4,566,706	4,703,707	4,844,819	4,990,163	5,139,868	5,294,064	5,452,886	5,616,473	5,784,967	5,958,516
91,167,357	93,382,880	93,116,859	92,842,856	92,560,634	92,269,945	91,970,535	91,662,143	91,344,499	91,017,326	90,680,338	90,333,240
40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000
51,167,357	**53,382,880**	**53,116,859**	**52,842,856**	**52,560,634**	**52,269,945**	**51,970,535**	**51,662,143**	**51,344,499**	**51,017,326**	**50,680,338**	**50,333,240**
24,400,000	20,800,000	16,400,000	11,200,000	6,000,000							
26,767,357	**32,582,880**	**36,716,859**	**41,642,856**	**46,560,634**	**52,269,945**	**51,970,535**	**51,662,143**	**51,344,499**	**51,017,326**	**50,680,338**	**50,333,240**
1,995,529	2,045,005	2,045,005	2,045,005	2,045,005	2,045,005	2,045,005	2,045,005				
								10,225,027	10,225,027	10,225,027	10,225,027
400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000				
								4,000,000	4,000,000	4,000,000	4,000,000
2,395,529	2,445,005	2,445,005	2,445,005	2,445,005	2,445,005	2,445,005	2,445,005	14,225,027	14,225,027	14,225,027	14,225,027
2,676,736	3,258,288	3,671,686									
			8,328,571	9,312,127	10,453,989	10,394,107	10,332,429	10,268,900	10,203,465	10,136,068	10,066,648
2,676,736	3,258,288	3,671,686	8,328,571	9,312,127	10,453,989	10,394,107	10,332,429	10,268,900	10,203,465	10,136,068	10,066,648
21,695,092	26,879,587	30,600,167	30,869,280	34,803,502	39,370,950	39,131,423	38,884,709	26,850,572	26,588,834	26,319,243	26,041,565
61,695,092	66,879,587	70,600,167	70,869,280	74,803,502	79,370,950	79,131,423	78,884,709	66,850,572	66,588,834	66,319,243	66,041,565
9.00%	11.00%	13.00%	13.00%	15.00%							
36,000,000	44,000,000	52,000,000	52,000,000	60,000,000	-	-	-	-	-	-	
25,695,092	22,879,587	18,600,167	18,869,280	14,803,502	79,370,950	79,131,423	78,884,709	66,850,572	66,588,834	66,319,243	66,041,565
61,695,092	66,879,587	70,600,167	70,869,280	74,803,502	79,370,950	79,131,423	78,884,709	66,850,572	66,588,834	66,319,243	66,041,565
1.51	1.44	1.36	1.47	1.40							
25,695,092	22,879,587	18,600,167	18,869,280	14,803,502	79,370,950	79,131,423	78,884,709	66,850,572	66,588,834	66,319,243	66,041,565

2046	**2047**	**2048**	**2049**	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	
21	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	
20	21	22	23	24	25	26	27	28	29	30	
14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	14.880	
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	10.416	
102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	102,250,271	
6,137,271	6,321,389	6,511,031	6,706,362	6,907,553	7,114,779	7,328,223	7,548,069	7,774,512	8,007,747	8,247,979	
6,137,271	6,321,389	6,511,031	6,706,362	6,907,553	7,114,779	7,328,223	7,548,069	7,774,512	8,007,747	8,247,979	
89,975,729	89,607,492	89,228,209	88,837,547	88,435,165	88,020,712	87,593,826	87,154,132	86,701,248	86,234,777	85,754,312	
40,000,000	40,000,000	40,000,000	40,000,000	40,000,000	40,000,000						
49,975,729	**49,607,492**	**49,228,209**	**48,837,547**	**48,435,165**	**48,020,712**	**87,593,826**	**87,154,132**	**86,701,248**	**86,234,777**	**85,754,312**	
49,975,729	**49,607,492**	**49,228,209**	**48,837,547**	**48,435,165**	**48,020,712**	**87,593,826**	**87,154,132**	**86,701,248**	**86,234,777**	**85,754,312**	
10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	10,225,027	
4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	4,000,000	
14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	14,225,027	
9,995,146	9,921,498	9,845,642	9,767,509	9,687,033	9,604,142	17,518,765	17,430,826	17,340,250	17,246,955	17,150,862	
9,995,146	9,921,498	9,845,642	9,767,509	9,687,033	9,604,142	17,518,765	17,430,826	17,340,250	17,246,955	17,150,862	
25,755,556	25,460,967	25,157,540	24,845,011	24,523,105	24,191,543	55,850,033	55,498,279	55,135,971	54,762,795	54,378,423	
65,755,556	65,460,967	65,157,540	64,845,011	64,523,105	64,191,543	55,850,033	55,498,279	55,135,971	54,762,795	54,378,423	
65,755,556	65,460,967	65,157,540	64,845,011	64,523,105	64,191,543	55,850,033	55,498,279	55,135,971	54,762,795	54,378,423	
65,755,556	65,460,967	65,157,540	64,845,011	64,523,105	64,191,543	55,850,033	55,498,279	55,135,971	54,762,795	54,378,423	
65,755,556	65,460,967	65,157,540	64,845,011	64,523,105	64,191,543	55,850,033	55,498,279	55,135,971	54,762,795	54,378,423	

Solar Project			ROE	FIRR	NPV					
Plant capacity (kW)	5,000		29.6%	14.11%	17,177,993					
						Energy rate		escalation		Financail outlay
O&M Cost (% of investment)	0.30%	of capital cost					**7.50**	0.225	**Rs./kWh**	Year 1
		Loan A	Equity	**140**	**Rs**					Year 2
Debt: Equity		45%	55%	**9**						
Total investment (Rs):	450,000,000	202,500,000	247,500,000	3%	p.a.	**escalation**	**3%**		**nine times**	
Depreciation	3%	linear over 25 yrs				Energy generation				
Interest rate loan A	11.00%					In a year	8,732,055	kWh		
Loan term for Loan A	12	years								
Insurance (of total investment)	0.01%									
							8,732,055			
		2025	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**
year		**1**	**2**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
				1	2	3	4	5	6	7
				7.500	7.725	7.950	8.175	8.400	8.625	8.850
Revenue:										
Total revenue in NRS		(225,000,000)	(225,000,000)	65,490,413	67,455,125	69,419,837	71,384,550	73,349,262	75,313,974	77,278,687
operational expenses										
Operation/maint... Cost (NRS)				1,350,000	1,390,500	1,432,215	1,475,181	1,519,437	1,565,020	1,611,971
Insurance				45,000	46,350	47,741	49,173	50,648	52,167	53,732
Operating Revenue		(225,000,000)	(225,000,000)	64,095,413	66,018,275	67,939,882	69,860,195	71,779,177	73,696,787	75,612,984
Depreciation				-	-	-	-	-	-	-
EBIT		**(225,000,000)**	**(225,000,000)**	**64,095,413**	**66,018,275**	**67,939,882**	**69,860,195**	**71,779,177**	**73,696,787**	**75,612,984**
Project IRR	14.11%									
Interest loan A	11.0%			22,275,000	21,384,000	20,381,625	19,267,875	18,042,750	16,706,250	15,258,375
EBT				**41,820,413**	**44,634,275**	**47,558,257**	**50,592,320**	**53,736,427**	**56,990,537**	**60,354,609**
Tax & Royalty										
Royalty (energy)	2%			1,309,808	1,349,102	1,388,397	1,427,691	1,466,985	1,506,279	1,545,574
Royalty (energy)	10%									
Royalty(capacity) $/kW	100			500,000	500,000	500,000	500,000	500,000	500,000	500,000
Royalty(capacity) $/kW	1000									
Total royalty				1,809,808	1,849,102	1,888,397	1,927,691	1,966,985	2,006,279	2,045,574
tax (after 7th year)										
1-7 years	0%			-	-	-	-	-	-	-
8-10 years	10%			-	-	-	-	-	-	-
<10 years	20%									
total tax				-	-	-	-	-	-	-
Net Profit				40,010,604	42,785,172	45,669,860	48,664,629	51,769,442	54,984,258	58,309,035
Net cash flow before principal payment				40,010,604	42,785,172	45,669,860	48,664,629	51,769,442	54,984,258	58,309,035
Principal repayment %	100%			4.00%	4.50%	5.00%	5.50%	6.00%	6.50%	7.50%
principal payment on loan	202,500,000			8,100,000	9,112,500	10,125,000	11,137,500	12,150,000	13,162,500	15,187,500
Cash flow after interest and principal repayment				31,910,604	33,672,672	35,544,860	37,527,129	39,619,442	41,821,758	43,121,535
Project cash flow		(225,000,000)	(225,000,000)	40,010,604	42,785,172	45,669,860	48,664,629	51,769,442	54,984,258	58,309,035
Nep present value (NPV)	**17,177,993**									
DSCR average/ minimu	**2.33**	**2.11**		2.11	2.16	2.23	2.30	2.38	2.47	2.48
Cash flow to equity	(247,500,000)	(123,750,000)	(123,750,000)	31,910,604	33,672,672	35,544,860	37,527,129	39,619,442	41,821,758	43,121,535
Return on investment	29.6%									
NPV of equity	$79,413,486.76									
Cost ($) per kW	**643**									

	loan	equity	total							
50%	101,250,000	123,750,000	225,000,000							
50%	101,250,000	123,750,000	225,000,000							
			450,000,000							
2034	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**
9	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**
8	9	10	11	12	13	14	15	16	17	18
9.075	9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300
79,243,399	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112
1,660,330	1,710,140	1,761,444	1,814,287	1,868,716	1,924,777	1,982,521	2,041,996	2,103,256	2,166,354	2,231,344
55,344	57,005	58,715	60,476	62,291	64,159	66,084	68,067	70,109	72,212	74,378
77,527,725	79,440,967	79,387,953	79,333,348	79,277,105	79,219,175	79,159,507	79,098,049	79,034,747	78,969,546	78,902,389
-	-	-	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000
77,527,725	**79,440,967**	**79,387,953**	**65,833,348**	**65,777,105**	**65,719,175**	**65,659,507**	**65,598,049**	**65,534,747**	**65,469,546**	**65,402,389**
13,587,750	11,583,000	9,132,750	6,237,000	3,341,250						
63,939,975	**67,857,967**	**70,255,203**	**59,596,348**	**62,435,855**	**65,719,175**	**65,659,507**	**65,598,049**	**65,534,747**	**65,469,546**	**65,402,389**
1,584,868	1,624,162	1,624,162	1,624,162	1,624,162	1,624,162	1,624,162	1,624,162			
								8,120,811	8,120,811	8,120,811
500,000	500,000	500,000	500,000	500,000	500,000	500,000	500,000			
								5,000,000	5,000,000	5,000,000
2,084,868	2,124,162	2,124,162	2,124,162	2,124,162	2,124,162	2,124,162	2,124,162	13,120,811	13,120,811	13,120,811
6,393,998	6,785,797	7,025,520								
			11,919,270	12,487,171	13,143,835	13,131,901	13,119,610	13,106,949	13,093,909	13,080,478
6,393,998	6,785,797	7,025,520	11,919,270	12,487,171	13,143,835	13,131,901	13,119,610	13,106,949	13,093,909	13,080,478
55,461,110	58,948,008	61,105,520	45,552,916	47,824,522	50,451,178	50,403,443	50,354,277	39,306,986	39,254,826	39,201,100
55,461,110	58,948,008	61,105,520	59,052,916	61,324,522	63,951,178	63,903,443	63,854,277	52,806,986	52,754,826	52,701,100
9.00%	11.00%	13.00%	13.00%	15.00%						
18,225,000	22,275,000	26,325,000	26,325,000	30,375,000	-	-	-	-	-	-
37,236,110	36,673,008	34,780,520	32,727,916	30,949,522	63,951,178	63,903,443	63,854,277	52,806,986	52,754,826	52,701,100
55,461,110	58,948,008	61,105,520	59,052,916	61,324,522	63,951,178	63,903,443	63,854,277	52,806,986	52,754,826	52,701,100
2.44	2.35	2.24	2.44	2.35						
37,236,110	36,673,008	34,780,520	32,727,916	30,949,522	63,951,178	63,903,443	63,854,277	52,806,986	52,754,826	52,701,100

2045	**2046**	**2047**	**2048**	**2049**	**2050**	**2051**	**2052**	**2053**	**2054**	**2055**
20	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
19	20	21	22	23	24	25	26	27	28	29
9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300	9.300
81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112	81,208,112
2,298,285	2,367,233	2,438,250	2,511,398	2,586,740	2,664,342	2,744,272	2,826,600	2,911,398	2,998,740	3,088,702
76,609	78,908	81,275	83,713	86,225	88,811	91,476	94,220	97,047	99,958	102,957
78,833,217	78,761,971	78,688,586	78,613,001	78,535,147	78,454,958	78,372,364	78,287,291	78,199,667	78,109,413	78,016,452
13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000	13,500,000
65,333,217	**65,261,971**	**65,188,586**	**65,113,001**	**65,035,147**	**64,954,958**	**64,872,364**	**64,787,291**	**64,699,667**	**64,609,413**	**64,516,452**
65,333,217	**65,261,971**	**65,188,586**	**65,113,001**	**65,035,147**	**64,954,958**	**64,872,364**	**64,787,291**	**64,699,667**	**64,609,413**	**64,516,452**
8,120,811	8,120,811	8,120,811	8,120,811	8,120,811	8,120,811	8,120,811	8,120,811	8,120,811	8,120,811	8,120,811
5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000
13,120,811	13,120,811	13,120,811	13,120,811	13,120,811	13,120,811	13,120,811	13,120,811	13,120,811	13,120,811	13,120,811
13,066,643	13,052,394	13,037,717	13,022,600	13,007,029	12,990,992	12,974,473	12,957,458	12,939,933	12,921,883	12,903,290
13,066,643	13,052,394	13,037,717	13,022,600	13,007,029	12,990,992	12,974,473	12,957,458	12,939,933	12,921,883	12,903,290
39,145,763	39,088,765	39,030,058	38,969,589	38,907,307	38,843,156	38,777,080	38,709,022	38,638,922	38,566,720	38,492,351
52,645,763	52,588,765	52,530,058	52,469,589	52,407,307	52,343,156	52,277,080	52,209,022	52,138,922	52,066,720	51,992,351
52,645,763	52,588,765	52,530,058	52,469,589	52,407,307	52,343,156	52,277,080	52,209,022	52,138,922	52,066,720	51,992,351
52,645,763	52,588,765	52,530,058	52,469,589	52,407,307	52,343,156	52,277,080	52,209,022	52,138,922	52,066,720	51,992,351
52,645,763	52,588,765	52,530,058	52,469,589	52,407,307	52,343,156	52,277,080	52,209,022	52,138,922	52,066,720	51,992,351

2056		
31		
30		
9.300		
81,208,112		
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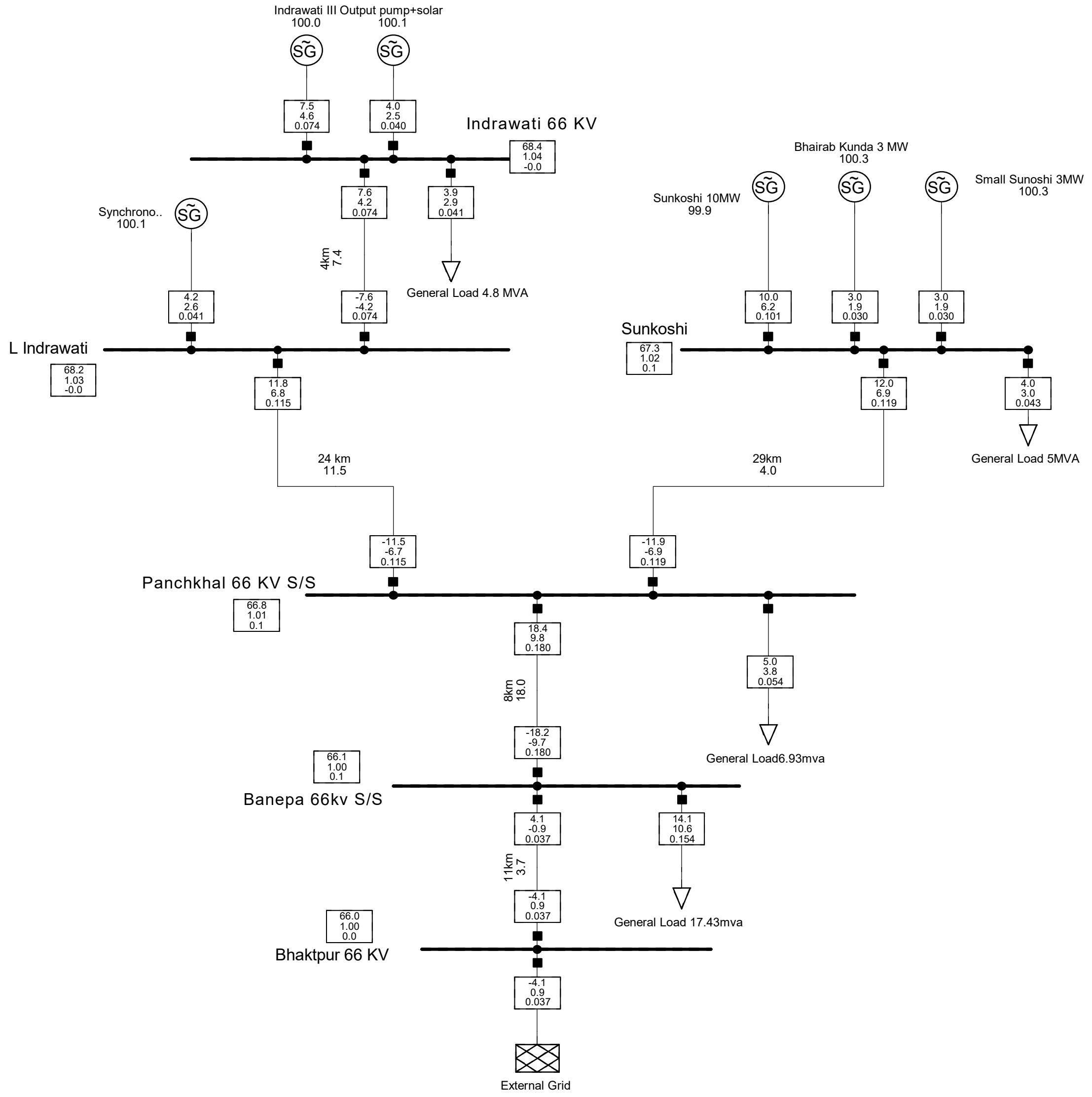

DIgSILENT

Load Flow Balanced	
Nodes	Branches
Line-Line Voltage, Magnitude [kV]	Active Power [MW]
Voltage, Magnitude [p.u.]	Reactive Power [Mvar]
Voltage, Angle [deg]	Current, Magnitude [kA]

PowerFactory 15.1.7

Project:
Graphic: Grid
Date: 4/12/2025
Annex:

GPTZero Version 2 025-03-13- base 1.- 4/28/2025

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- **Matched Sources**:
    - Definitions and standard descriptions (e.g., solar PV, hybrid systems) match with general references like IRENA, SolarQuarter, EMBER (with citations included)
    - A few descriptions (particularly in *literature review* and *background* sections) closely match commonly available public resources, but they are **properly cited.**
- **No major plagiarism detected** — your thesis is **original and acceptable** for academic submission standards.