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Modeling, Simulation, and Performance Analysis of Large Scale Solar Power Plant in Nepal Under Single and Double Axis Tracking Systems

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Abstract

Nepal Electricity Authority intends to establish an energy mix that consists of 15% solar energy and 85% hydropower energy. Nepal has huge solar potential but has limited land area as compared to larger countries. Solar power plant with capacity greater than 1 MW or large-scale grid-tied solar power plant with a tracking system, therefore, has greater potential in Nepal. This study compares and analyzes the technical and economical evaluation of large-scale grid-connected PV projects in five different locations of Nepal. The study also analyses the importance of scaling up the share of solar energy to contribute to country's overall energy generation mix. PVSyst software is used to undertake a thorough technical and economic study based on annual energy output, payback period, and Levelized cost of energy. The simulated results is validated by analytical calculations using different formulas. A 6.6 kWp vertical single-axis and double-axis tracking system consisting of 20 solar modules of 330 W is designed and its motor selection is also done. The results of this study show that PV plants are technically and economically feasible for all five locations. Jumla is the most feasible location with the highest annual generation of 18,222 MWh, the highest capacity utilization factor of 20.39%, the lowest cost of energy of 4.77 NRs/kWh, and the shortest payback period of 7.34 years for fixed-tilt orientation. Similarly for vertical single-axis tracking and double-axis tracking the annual energy output for Jumla is 21,858.77 MWh and 24,565.45 MWh respectively. In average for all location, a vertical single-axis tracking system generates an average of 14.57% more energy annually than a fixed-axis system, while a double-axis tracking system generates 22.43% more energy annually as compared to fixed-axis system. The analytical result validates the simulation results as it shows around 21.2% energy gain from double-axis tracking when compared to fixed-axis tracking.

Keywords

energy mix, PVSyst, tracking sytem, capacity utilization factor

1. Introduction

In recent years, large-scale power generation across the globe has turned to one of the most promising renewable energy sources: solar energy. [1]. The installation of the solar PV system is rapidly rising, reaching about 760 GW up-to the end of 2020 from 621 GW in 2019, and it is expected to reach around 1650 GW by 2023 and 4,600 GW by 2050 mitigating 4 Giga tons of CO_2 emissions annually [2]. A total of 139 GW was added in 2020 although the world was disrupted by the COVID-19 pandemic. PV is thus a fast-growing market with a 32 % annual growth rate of cumulative PV power plant installations during the period 2010 to 2019 [3]. According to International Energy Agency (IEA), among this net total capacity as of 2020 64% share was of utility-scale PV installations whereas the rest 36% was of commercial/industrial and residential rooftop systems.

In large-scale PV plants, the PV solar modules are mostly installed at a yearly optimum fixed-tilt angle for a location. These can, however, also be set up with sun tracking devices or at a seasonal optimal tilt. Therefore, a solar tracking system is used rather than a fixed system to boost system production. By altering the PV system orientation such that it is constantly facing the sun, the efficiency of the entire system is increased. The two primary types of solar tracking systems are active and passive tracking systems [4]. Single-axis tracking and double-axis tracking systems are additional categories for the active system. Although it is still much smaller than the fixed system, the share of solar tracking panels is growing quickly. While the global demand for tracking systems was 14.5 GW in 2017 out of 104 GW of new solar capacity added (14%)[5], it was 25 GW in 2018 out of 103 GW installed (24%)[2]. Additionally, it is anticipated that between 2019 and 2025, the solar tracking industry would develop at a 32 percent compound annual growth rate (CAGR) [6]. Solar developments implementing tracking systems are becoming more common due to a fall in the price of panels and the implementation of bi-facial technology. These factors have led to higher energy production and lower Levelized cost of electricity.

The solar energy resources in Nepal are abundant. Nepal has a solar potential of 50,000 TWh/year, which is 7,000 times more than its current electricity consumption and 100 times more than its hydropower resource [7]. The average global solar radiation in Nepal ranges from 3.6 to 6.2 kWh/m^2day with an average of 4.7 kWh/m^2day (=16.92 MJ/m^2day) and the sun shines for about 300 days per year in Nepal [8]. 2,100 MW is estimated to be the commercial potential of solar energy for grid connection in Nepal [9]. Future energy demands in Nepal can simply be satisfied by solar. As per the Department of Electricity Development Nepal(DOED), 20.18 MW of electricity from 4 solar power plants is connected to the national grid. 22 solar power plants with a total of 137.56 MW capacity have got the construction license and 44 solar power plants with a total capacity of 1239.69 MW have got survey license as of July 2022. Similarly, 3 solar power plants with a capacity of 15 MW have applied for a construction license and 20 solar power plants with a total capacity of 197.4 MW have applied for survey license.

Nepal's reported annual electricity consumption for the fiscal year 2020/2021 was 7319 GWh [11]. This record surpasses the prior figure of 6,529 GWh for the 2019–2020 fiscal year. The installed capacity of the hydroelectricity was 1278 MW by the end of the fiscal year 2020–2021 [12]. According to Nepal Electricity Authority (NEA), the peak electricity demand in 2020–2021 was roughly 1539 MW [13]. Therefore, more power was imported from India to meet the demand. Per capita electricity consumption for the fiscal year 2020/21 has reached 260 kWh [11]. The goal set forward by the Government of Nepal is to reach per capita power consumption of 700 kWh by 2021–2022 and 1500 kWh by 2026–2027 [14]. The government's goal is for the country to have an 8.5 percent economic growth rate by 2030, placing it on the list of middle-income nations. It is expected that the higher per capita power usage would help them achieve this goal [15]. Nepal must raise its electricity usage in order to achieve this greater economic growth rate [16]. The majority of homes, even those with access to electricity, frequently use it solely for lighting due to a lack of supply and low income. According to the 2019 Energy Progress Report, 1.3 million people do not have access to electricity, and Nepal has set a goal of providing electricity to everyone by the year 2023 [14]. Hence the PV system is the one that should be targeted.

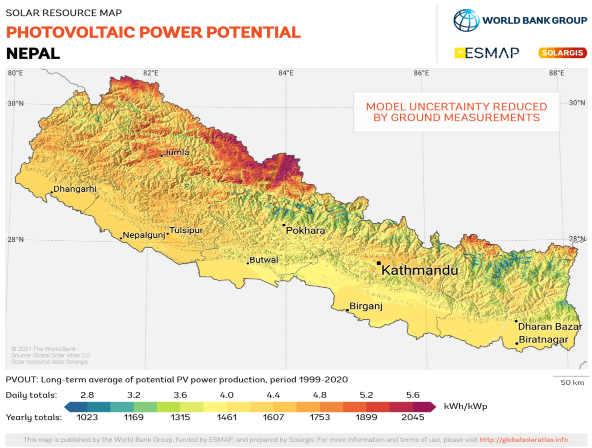


Figure 1: Photovoltaic Potential in Nepal. [10]

In Nepal, a grid-connected solar system is in its emerging phase. There is a wide range of possibilities in commercial PV power plants in Nepal. NEA intends to establish an energy mix that consists of 15% solar energy and 85% hydropower. Even yet, hydropower dominates the majority of the nation's power system. It is crucial to integrate alternative renewable energy technologies, such as solar PV, into the nation's energy mix due to the nature of hydropower, which is mostly dominated by run-off from river types and the linked inconsistent power supply during the dry season. As per research, Nepal has 28% of agricultural land, 40% of forest land and 12% of pastures out of the total land. So Nepal having a smaller area and limited land as compared to other larger countries like China and India now has even more potential for tracking solar systems to increase the solar PV generation to meet the energy mix. Tracking system will increase production i.e. with less area more power can be generated.

2. Methodology

A comprehensive analysis of the literature led to the modeling of an 8.5 MW solar power plant in 5 different Nepal locations with fixed, vertical single-axis tracking, and double-axis tracking conditions. Dharan, Jumla, Kathmandu, Lumle, and Nepalgunj were the locations selected. To provide the PVSyst V7.2 with as many realistic parameters as possible, an entire setup of real solar panels and inverter systems was created. Analytical computations were carried out with the aid of ground-based solar radiation data and formulas to validate simulation results. In the end, technical parameters that were simulated and analytically derived were compared, examined, and discussed. Microsoft Excel was also used to conduct a thorough PV system economic analysis. And finally, a 6.6 kWp tracking system was designed and its electricity consumption was calculated. To achieve 8.5 MW by the tracking system, the identical 6.6 kWp tracker is multiplied in numbers. The analytical calculations and simulation for tracking system was done considering self consumption. For economic analysis, the motor consumption which was calculated in this study was deducted from the simulated annual energy production.

2.1 Site Selection

Five sites were identified as potential locations based on survey licenses or construction licenses provided by the Department of Electricity Development for a solar plant of a capacity of more than 4 MW. Another important reason behind choosing these sites was that the World Bank Group had collected ground-based solar radiation data for these sites which was used in this study for analytical calculation. Latitude, longitude, ambient temperature data, altitude data and solar radiation data consisting of Global Horizontal Irradiation (GHI), Direct Normal Irradiation (DNI), and Diffused Horizontal Irradiation (DHI) were collected for the selected location. Table 1 shows the detail of selected sites.

2.2 Air Temperature

The operating environment and performance effectiveness of solar power systems are influenced by the air temperature. Higher air temperatures in PV power plants lower the efficiency in the power conversion of the PV modules.

2.3 Solar Radiation Data

The daily average solar radiation data for selected sites are shown in Table 3. GHI, DNI and DHI are expressed in terms of kWh/m^2/day.

2.4 System Description

8.5 MW grid-tied solar power plant system is considered for all 5 selected locations. The proposed solar panel is the Waaree 330 Wp SPV MODULE with a rating of 330W. The panels are set up in strings to attain the current and voltage ratings necessary to meet the inverter's specifications. To match the voltage and current in this instance, 1550 such strings are linked to the inverter input stage in parallel and 20 modules, each of which is 330 W, are joined to form a string in series. For this plant, a total of 31,000 panels are required. An array of 3,100 modules are connected to an inverter and there are 10 such arrays. The output of the inverter is connected to the national grid. The design layout is displayed in Figure 2. Table 4 shows the technical specification of the PV module.

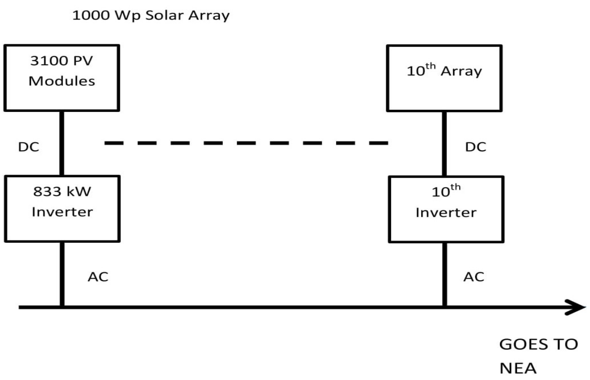


Figure 2: Design Layout

The inverter used for this plant is Solar Ware 833 - PVL-L0833GR Inverter made by TMEIC. The selected inverter has a rated power of 833 kW. The output ac voltage is 418 V with 98.75 percent inverter efficiency. 10 inverters are used to match the output energy of 8.5 MW. Table 5 shows the technical specifications of the inverter.

Table 1: Selected Sites for Study

S.n	Site Name	Latitude	Longitude	Altitude(m)	Measurement Station Host
1	Dharan	26.79291°	87.29263°	315	Institute of Engineering, Purwanchal Campus
2	Jumla	29.27237°	82.19351°	2363	Hotel Kanjirowa
3	Kathmandu	27.68157°	85.31868°	1315	Institute of Engineering, Pulchowk Campus
4	Lumle	28.29666°	83.81800°	1742	DHM Agro-Meteorological Station
5	Nepalgunj	28.11302°	81.58899°	150	Agricultural Research Council, Regional Agricultural Research Station

Table 2: Monthly averages of air-temperature at 2 m at 5 sites [10]

Month	Temperature(°C)				
	Dharan	Jumla	Kathmandu	Lumle	Nepalgunj
Jan	15.2	1.2	10.5	5	13.9
Feb	18.7	3.3	13.4	7	17.9
Mar	23.2	7.1	17.1	9.9	23
Apr	26.7	11.5	20.6	13.5	28.4
May	27.6	14.8	21.9	15.9	30.6
Jun	28	17.7	23.4	18.4	30.8
Jul	27.6	18.7	23.2	19.2	29
Aug	27.8	18.5	23.3	19.2	29.1
Sep	27	16.9	22.4	18.1	28.4
Oct	24.7	12.5	19.6	14.4	25.3
Nov	20.7	8.7	15.5	10.5	20.1
Dec	16.7	5.2	12	7.4	15.5
Year	23.7	11.3	18.6	13.2	24.3

2.5 Analytical Calculation

For this, the average insolation for all locations was obtained from ground-based solar radiation data. For the fixed system Global Horizontal Irradiation (GHI) was used and for the double-axis system, the sum of Direct Normal Irradiation (DNI) without cosine component and Diffused Horizontal Irradiation (DHI) was used. Along with the insolation, the average temperature was also used for calculation. The average temperature was used directly to calculate the cell temperature (which is generally 30-45 degrees more than ambient temperature). The power degradation factor and power efficiency of the system were defined and the total energy and specific yield were calculated.

$$CellTemp(Tcell) = Ambient\ Temperature(°C) + 30°C \tag{1}$$

$$DegradationFactor = [1 - (Tcell - 25) \times \alpha\ for\ Pmax] \tag{2}$$

Where α for Pmax is specified in PV module specification.

$$Efficiency(\eta) = (Losses \times Temp.\ Factor) \tag{3}$$

Where Losses include Ohmic Losses, Module Efficiency Losses, Light Induced Degradation Losses, Module Mismatch Losses at MPP, Soiling Losses, Induced Angle Modifier (IAM) Losses and Grid Outtage Losses. The loss values were used the same for analytical calculation and simulation.

Monthly Generated Energy is given by

$$E = Average\ Insolation\ (kWh/m^2) \times Module\ Area\ (m^2) \times \eta \times No.\ of\ days\ in\ month \tag{4}$$

Capacity Factor is given as

$$CF = \frac{Actual\ Energy\ Generated\ (kWh)}{Installed\ Capacity\ at\ STC\ (kW) \times 365 \times 24} \tag{5}$$

3. Definitions of Technical and Economic Parameters

The major technical parameters are specific yield (SY), Annual energy production (AEP), Performance Ratio (PR) and Capacity utilization Factor (CUF). The economic parameters studied are Net Present Value (NPV), Internal Rate of return (IRR), Levelized Cost of Electricity (LCOE) and Payback period.

3.1 Specific Yield (SY)

One of the most widely used performance metrics for solar systems is Specific Yield (kWh/kWp). The proportion of total annual energy produced to the installed solar capacity is known as the Specific Yield. The specific yield normally ranges from 3 to 6 kWh/kWp/day in Nepal.

$$SY = \frac{Plant\ Output(kWh)}{Installed\ Capacity(kWp)} \tag{6}$$

3.2 Annual Energy Production (AEP)

The total amount of electrical energy a solar power plant generates over the course of a year, expressed

Table 3: Solar Radiation Data for Selected Site [10]

Month	Dharan			Jumla			Kathmandu			Lumle			Nepalgunj		
	GHI	DNI	DHI	GHI	DNI	DHI	GHI	DNI	DHI	GHI	DNI	DHI	GHI	DNI	DHI
Jan	3.52	3.49	1.47	3.99	6.64	1.15	3.73	4.29	1.28	3.82	5.19	1.30	2.99	2.66	1.44
Feb	4.34	3.68	1.90	4.85	6.94	1.76	4.45	4.48	1.55	4.36	4.79	1.72	4.44	4.16	1.99
Mar	5.64	4.55	2.26	6.20	7.67	1.59	5.58	5.21	1.77	5.46	5.08	1.88	6.00	5.68	2.14
Apr	6.16	4.27	2.89	6.68	6.82	2.21	6.05	4.96	2.53	5.97	4.35	2.28	6.76	5.56	2.84
May	5.85	3.43	3.05	6.91	6.33	2.66	5.80	3.94	2.60	5.74	3.42	2.87	6.77	4.73	3.24
Jun	5.13	2.50	3.24	6.05	4.80	2.89	5.29	2.86	2.76	5.07	2.27	2.87	5.77	3.44	3.23
Jul	4.62	2.41	2.90	4.69	2.73	2.54	4.54	2.17	2.78	4.01	1.27	2.67	4.87	2.54	2.81
Aug	4.73	2.59	2.88	4.74	3.20	2.46	4.62	2.39	2.56	4.07	1.46	2.50	4.80	2.65	2.89
Sep	4.39	2.84	2.32	5.24	5.23	2.01	4.51	2.90	2.03	4.18	2.08	2.11	4.80	3.26	2.55
Oct	4.68	4.64	2.17	5.70	8.17	1.13	4.95	5.05	1.58	4.62	4.21	1.41	4.92	4.65	2.21
Nov	4.21	5.09	1.72	4.77	8.11	0.92	4.19	4.99	1.14	3.94	4.71	1.14	4.08	4.34	1.59
Dec	3.64	4.47	1.50	4.10	7.61	0.72	3.65	4.56	0.84	3.58	4.97	0.70	3.21	3.34	1.27
Year	4.74	3.66	2.36	5.33	6.18	1.84	4.78	3.98	1.95	4.57	3.65	1.95	4.95	3.91	2.35

Table 4: PV Panel Specification

Description	Values
Pmax	330Wp
V mp	36.55V
I mp	9.03A
Voc	45.6V
Isc	9.4A
Efficiency	17.01%
Dimensions	(1960x990x40)mm
Weight	22.5Kg
α *at Pmax*	0.37

Table 5: Inverter Specification

Model		PVL-L0833GR
Output Side(AC)	Rated Power	833Kw
	Rated Voltage (3-phase)	418V +10%, -12%
	Rated Frequency	60/50 Hz (+0.5 Hz, -0.7 Hz)
	Power Factor Range	0.91 Lead/Lag
	Maximum Current	1438 Arms @368Vac/88%
	Max. Efficiency	99.00%
	CEC Efficiency	98.50%
Input Side (DC)	Maximum Voltage	1000 Vdc
	MPPT Operation Range	605 Vdc -950 Vdc
Cooling Method		Advanced Hybrid Cooling
Standard Number of Inputs		1
Weight		7940 lbs (3600kg)
Dimensions (H x W x D)		(2286 x 3000 x 1150)mm

in kilowatt-hours or megawatt-hours, is known as its annual energy production (AEP) (kWh or MWh). It is denoted by AEP.

3.3 Performance Ratio (PR)

The performance ratio is the comparison of actual energy output to what is theoretically feasible. It is frequently referred to as a quality factor because it is a measurement of a PV plant's quality that is independent of location. The relationship between the PV plant's actual and theoretical energy production is described by the performance ratio (PR), which is expressed as a percentage. A solar power facility that is highly efficient should have a Performance Ratio of 75% or above.

$$PR = \frac{Actual\ Energy\ From\ Plant(kWh)}{Calculated\ Nominal\ Plant\ Output(kWh)} \tag{7}$$

3.4 Capacity Utilization Factor (CUF)

It is the ratio of a solar power plant's actual annual output to its maximum annual output under ideal circumstances. Typically, the capacity utilization factor is represented as a percentage.

$$CUF = \frac{Actual\ Energy\ From\ Plant(kWh)}{Plant\ capacity(kW) \times Available\ hours(h)} \tag{8}$$

3.5 Levelized Cost of Energy (LCOE)

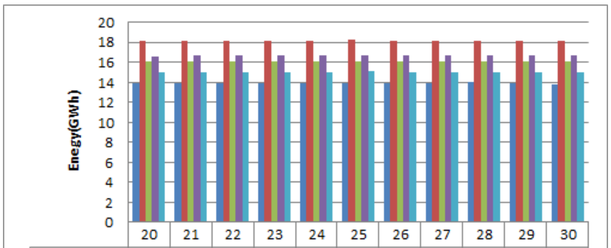
LCOE is given by the total cost to build and operate the power plant over its lifetime divided by the total energy output of the asset over that lifetime. It should be always lesser than the grid tariff rate. It is given as:

$$LCOE = \frac{NPV\ of\ Total\ Cost}{NPV\ of\ total\ energy\ produced} \tag{9}$$

4. Results and Discussions

4.1 Optimum Tilt Angle

For selecting the optimum tilt angle, PVSyst simulation was done for all study locations under fixed conditions and varying tilt angles from 20 to 30 degrees. As Figure 3 shows The best result for all locations was for 25 degree, so the optimum tilt was chosen to be 25 for the study.



	20	21	22	23	24	25	26	27	28	29	30
Dharan	13.97	13.97	13.98	13.98	13.97	13.96	13.94	13.92	13.99	13.87	13.84
Jumla	18.11	18.14	18.16	18.18	18.19	18.22	18.20	18.19	18.18	18.17	18.15
Kathmandu	16.06	16.09	16.11	16.13	16.13	16.15	16.14	16.13	16.12	16.10	16.08
Lumle	16.64	16.67	16.69	16.71	16.71	16.73	16.72	16.71	16.69	16.68	16.65
Nepalgunj	15.02	15.04	15.05	15.07	15.07	15.08	15.07	15.05	15.04	15.02	15.00

Figure 3: Optimum Tilt Angle

4.2 Simulation Results

The Annual Energy Production (AEP) in terms of MWh after motor consumption is given in Table 6 for fixed, vertical single-axis tracking (VSAT) and double-axis tracking (DAT) system for all location.

From Table 6, it is seen that the best location as per annual energy production after motor consumption is Jumla among the study locations. According to simulation, the VSAT system often outperforms the fixed systems by 14.57 %, while the DAT system outperforms fixed systems by 22.43 %.

Table 7 represents the CUF for fixed, single-axis and double-axis tracking sytem for all 5 study locations. It can be clearly seen that the CUF of the DAT system is significantly higher than the CUF of the fixed and VSAT system. From table, it is seen that Jumla has the highest CUF among the study locations as it has more annual energy production.

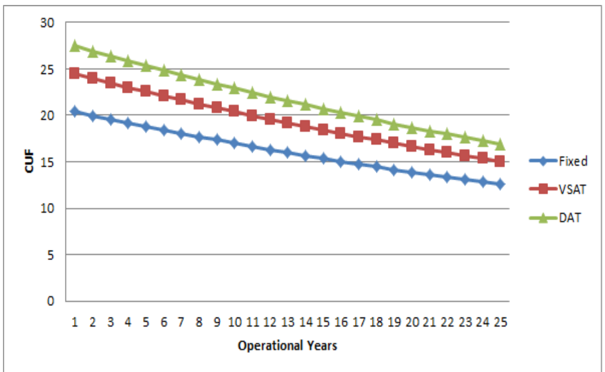


Figure 4: Capacity Utilization Factor comparison for Jumla

The capacity utilization factor is anticipated to decline annually as a result of the solar panel's deterioration. Figure 4 shows the comparison of CUF over a period of 25 years for all three systems in Jumla. A similar trend is exhibited in Dharan, Kathmandu, Lumle and Nepalgunj.

Performance ratio comparison for all locations is given in Figure 5.

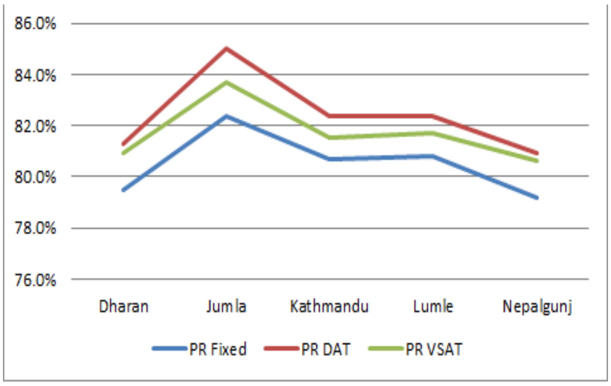


Figure 5: Performance Ratio Comparison

From Figure 5, it is clear that the performance ratio of double-axis system is greater than that of single-axis system and fixed-axis system. Jumla has the best performance ratio among the selected sites. It is due to the better solar radiation property and lesser ambient temperature of Jumla among the selected study locations.

4.3 Analytical Calculation Results

In order to validate the simulation results, analytical calculations were performed using ground-based solar radiation data. Annual Energy Production and Specific Yield was calculated for the fixed system and Double Axis Tracking system using GHI, DNI and DHI.

From table 8 it is seen that, for analytical calculation, there is an average increase of 21.2% energy for DAT system when compared to the fixed system. So, motor consumption on average is only 1.2% for single axis motor and 1.6% for double axis motor out of total energy produced. Analytical calculation results came close to the simulated results which helps to validate the simulated results.

4.4 Design of Double Axis Tracker

Simulation and analytical results show that there is an average increase of 23% energy output from the double axis tracking system as compared to the fixed

Table 6: Simulation Results After Motor Consumption

Location	Fixed AEP (MWh)	VSAT AEP (MWh)	DAT AEP (MWh)	Fixed vs VSAT AEP (MWh)	Fixed vs DAT AEP (MWh)
Dharan	13964	16015.77	17218.45	12.8%	18.9%
Jumla	18222	21858.77	24562.45	16.6%	25.8%
Kathmandu	16152	19028.77	21158.45	15.1%	23.7%
Lumle	16734	19827.77	22077.45	15.6%	24.2%
Nepalgunj	15079	17271.77	18743.45	12.7%	19.6%
Average				14.57%	22.43%

Table 7: Comparison of CUF at first year of operation

Location	Capacity Utilization Factor (%)		
	Fixed	VSAT	DAT
Dharan	15.63	17.92	19.27
Jumla	20.39	24.46	27.49
Kathmandu	18.08	21.30	23.68
Lumle	18.73	22.19	24.71
Nepalgunj	16.88	19.33	20.98

Table 8: Analytical Results After Motor Consumption

Location	Fixed AEP(MWh)	DAT AEP(MWh)	Fixed vs DAT Difference (%)
Dharan	13,952	17339.45	19.54%
Jumla	16,476	24478.45	32.69%
Kathmandu	14,362	17456.45	17.73%
Lumle	14,035	16854.45	16.73%
Nepalgunj	14,487	17953.45	19.31%
Average			21.20%

system. So a 6.6 kW tracking system is designed. Both vertical axis tracking system and double axis tracking system is designed. Every configuration is kept same. Only difference is that the double axis tracking system uses extra linear actuator for elevation tracking. Otherwise both the tracking system consists of a slewing drive motor for azimuth rotation. It is then modeled in Solidworks and motor selection calculation is done. It rotates 180 degrees throughout the day from east to west and 15 to 45 degrees elevation-wise. The controller is based on astronomical tracking configuration (open loop method) as it decreases the cost of different sensors and is also easy to control. As using a motor every minute is more consuming, 10 hrs of tracking period is considered and every hour it rotates by 18 degrees and changes its elevation by 3 degrees. In conclusion, the motor is active 11 times every day (10 times for rotating as per the sun and 1 time in the evening to reset to the original position for tomorrow).

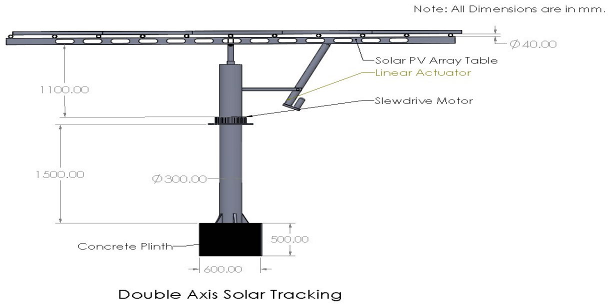


Figure 6: Double Axis Tracker Drawing

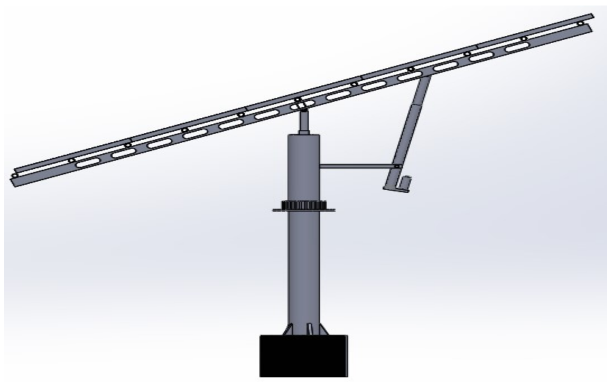


Figure 7: Double Axis Tracker 3D Model

4.5 Mounting System

The structure that supports the solar panels is referred to as the mounting system; the structure is made up of moveable and fixed pieces according to a predetermined set of criteria.

First and foremost, the structure must be strong enough to handle the weight of the solar panels that are attached to it. Twenty solar panels(each 22.5 kg) are used in this design. In addition, the column and base of the structure should be strong enough to sustain the weight of the frame. It is estimated to be 250 kg. This results in a total weight that is around 700 kg.

Secondly, because it will be built outside, it must be able to withstand the effects of the sun's heat, rain water, and wind. The impact of wind load on the structure when wind load is exerted upon the solar panels will be of the utmost importance. Based on Nepal's National Building Code, a basic wind speed of 55 m/s is used to compute wind loads [17]. Assuming the maximum area of the solar panels will be exposed to the wind, the wind loads are calculated using the following general formula:

$$Wind\ load : Force,\ F = A \times P \times Cd \tag{10}$$

Where,

A = Area = (8m × 5 m) = 40 m^2

P = Wind pressure (Psf), = 0.00256 × V^2 (V = wind speed 55 m/s)

= 0.00256 × $(123.031)^2$ = 38.73 Psf =0.2689 Psi

= 189 Kg/m^2

Cd = Drag coefficient, = 2 for flat plates

So, Wind load force = A × P × Cd = 40 m^2 × 189 kg/m^2 × 2 = 15120 kg= 148327.2 N

According to the calculation, the material used would have to be able to sustain an acting force perpendicular to it of 148327.2 N.

4.6 Motor Selection and Consumption

4.6.1 Slew Drive Motor

Slew drive motor and linear actuator is used in the design as tracking motor. For Slew drive motor torque is calculated as:

Dead Load Weight(Without Wind)= $m \times g = 700 \times 9.81 = 6867N$

For Normal condition wind velocity is assumed to be 15 m/s.

So,

Wind Load = $A \times P \times Cd$

$$= 40m^2 \times \{0.00256(33.554)^2 Psf \times 2$$

$$= 40m^2 \times 14kg/m^2 \times 2$$

$$= 1120kg = 11200N$$

Total Output Load $= 11200 + 6867 = 18067N$

Then,

Load Torque = Output Load × Distance

$$= 18067 \times 1.1m = 19873.7N.m$$

So for this output torque, slew drive motor WGWEA 21 with reduction ratio 90:1 is chosen[18].

Required input motor torque = Load torque/Speed ratio/0.4 [18] =19873.7/90/0.4=552 N.m

Required input motor speed = load speed x reduction ratio[18] Slew drive motor is designed to be rotated at 3 °per minute.

So,

Motor Speed = (3 x π / 180) x 90 =4.71 Rpm

Then Power = (RPM x Torque)/9.5488 = 0.27kW

Tracker is designed to rotate 3 degree per minute and total tracking hours is considered 10 hrs. But the tracker will rotate 1 times per hour(18 °) for 10 times a day and 11th rotation will be whole 180 °to come to its initial position. So total power consumption is given as:

Power consumption per day= 10(0.27 x 0.1) + (0.27x1)=0.54 kWh

4.6.2 Linear Actuator

The main selection criteria for linear actuator is the maximum force it has to move. So the maximum force is calculated against the weight load at 90 degree. Maximum Force=mxgxsinθ=700x9.81x1=6867 N

So based on maximum force, a 12 V DC and 24 Amperage linear actuator with 1000mm stroke length is selected for design.

Linear motor is used for elevation change from 15 °to 45°. So total tracking angle is 30 °for 10 hrs of tracking time. The motor will be running 1 time per hour so that is equivalent to 3 degree per hour and at the end of the day it will reset to its original position for next day. So power consumption per day is given as:

Power Consumption =VxIxt

=12x24x(10x0.1+0.1)=3168 Wh=0.3168 kWh

4.7 Control Strategy

The open loop tracking strategy is used for the design because of its simplicity and cost efficiency. A closed loop tracking system would be more effective as it will have more tracking frequency. But more tracking frequency leads to more movement of the tracking motor. It will lead to more mechanical wear as well as more energy consumption. So to mitigate these limitations, open loop control system with predefined control timing is set and the tracking is achieved. In this design, the slew drive motor will rotate for 18 °per hour in order to rotate 180 °from East to West per day and the linear motor will track 3 °per hour in order to change elevation by 30 °per day. Figure 8 shows the simple flowchart for the open loop control strategy.

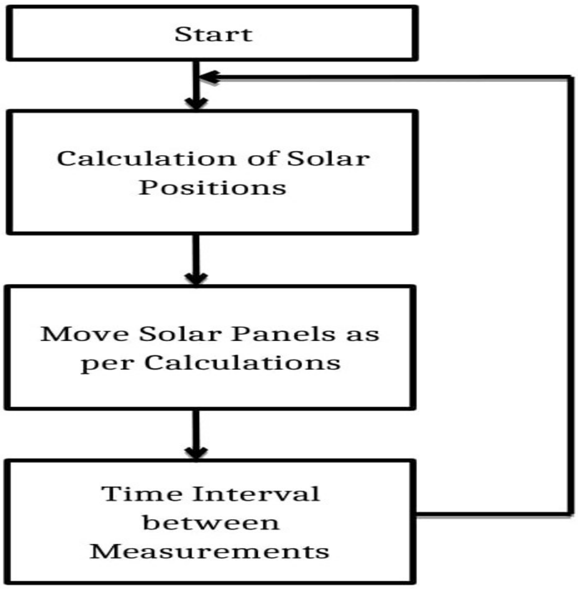


Figure 8: Open Loop Control System

4.8 Economic Analysis

All product costs, shipping costs, customs taxes, VAT, and system degradation factors have been taken into account for the economic analysis. Project life was assumed to be 25 years, system output was assumed to degrade by 0.5% annually[19]. Land leasing cost was assumed to be same for all locations for simplification. Operation and Maintenance cost is assumed to be 3% of the total cost for fixed, VSAT and DAT system respectively . Fixed system, VSAT system and DAT system are subjected to increase 3%, 4% and 5% respectively every year [19]. Other costs are taken from an under-construction 10 MW solar project in Jhapa as reference. The price from the Alibaba store is taken as a reference for the cost of the single-axis tracking system and double-axis tracking system. 70% Loan and 30% Equity model is assumed. PPA is considered to be done at Rs 7.3 for 25 years of operation. The discount rate is considered to be 7.8%. The transportation and logistics cost is not taken into consideration for the study. The total cost per MW for fixed system was NRs. 7.06 Crore, VSAT system was NRs. 7.69 Crore and for DAT system was NRs. 7.9 Crore.

IRR, Payback period and LCOE for all location was calculated and the results were as per Table 9.

Table 9: Economic Analysis Results

	NPV in Crores (NRs)	Project IRR (%)	Equity IRR (%)	LCOE (NRs/kWh)	Simple Payback Period (Years)	Discounted Payback Period (Years)
Dharan						
Fixed	14.97	11.4	15.52	6.11	7.56	12.4
VSAT	19.2	12.1	17.62	6.05	7.11	11.26
DAT	21.97	12.71	19.56	5.96	6.75	10.33
Jumla						
Fixed	41.3	17.23	31.75	4.77	5.39	7.34
VSAT	55.3	19.44	38.66	4.55	4.81	6.33
DAT	67.39	21.69	45.86	4.3	4.34	5.55
Kathmandu						
Fixed	28.5	14.45	23.78	5.33	6.26	9.06
VSAT	37.8	15.97	28.41	5.16	5.7	7.94
DAT	46.34	17.64	33.67	4.93	5.19	7
Lumle						
Fixed	32.1	15.24	26.01	5.16	5.99	8.5
VSAT	42.74	16.96	31.29	4.97	5.42	7.41
DAT	52.02	18.75	36.96	4.74	4.93	6.54
Nepalgunj						
Fixed	21.86	12.97	19.71	5.68	6.83	10.42
VSAT	26.93	13.74	22.1	5.64	6.45	9.53
DAT	31.41	14.67	25.04	5.51	6.04	8.68

From Table 9 it is seen that Jumla is the most economically feasible location for large scale among the study locations with least levelized cost of energy of 4.77 NRs/kWh, 4.55 NRs/kWh and 4.3 NRs/kWh for the fixed, VSAT and DAT systems respectively.

Table 10: Comparison of IRR

Location	Project IRR (%)			Fixed vs VSAT	Fixed vs DAT
	Fixed	VSAT	DAT		
Dharan	11.4	12.1	12.71	5.79%	10.31%
Jumla	17.23	19.44	21.69	11.37%	20.56%
Kathmandu	14.45	15.97	17.64	9.52%	18.08%
Lumle	15.24	16.93	18.75	9.98%	18.72%
Nepalgunj	12.97	13.74	14.67	5.60%	11.59%

Table 10 represents comparison of project IRR for selected sites. It is seen from table that the project IRR of Jumla is 11.37% highger for VSAT when compared with the fixed system and it is 20.56% higher for DAT as compared to the fixed system. Similarly, Table 11 represents comparison of LCOE for selected sites. It is

Table 11: Comparison of LCOE

Location	LCOE (NRs/kWh)			Fixed vs VSAT	Fixed vs DAT
	Fixed	VSAT	DAT		
Dharan	6.11	6.057	5.96	0.88%	2.52%
Jumla	4.77	4.55	4.3	4.84%	10.93%
Kathmandu	5.33	5.16	4.93	3.29%	8.11%
Lumle	5.16	4.97	4.74	3.82%	8.86%
Nepalgunj	5.68	5.64	5.51	0.71%	3.09%

seen that the LCOE of Jumla is 4.84% lesser for VSAT when compared with the fixed system and it is 10.93% lesser for DAT as compared to the fixed system.

From all the above results, on average, there is a 14.57% improvement that VSAT has over fixed systems and a 22.43% improvement for DAT over the fixed system. This falls in the range of 12%-50% improvement which supports the previous studies for solar tracker [20].

Also the results of the study was compared to the actual generation from 8.5 MW Butwal Solar Power Plant. The actual monthly average kWh/kWp from Butwal Solar Power Plant for fixed-axis system is 117 kWh/kWp/month. The simulated monthly average kWh/kWp for the study locations for fixed system was calculated to be 130 kWh/kWp/month, which is slightly more than the actual generation data. It further validates the study as there is only slight variation in actual and simulated results. Simulation results are better because PVSyst tries to utilize the best models (or the most appropriate) for simulating each component of the system and taking into account each behavior.

5. Conclusion

Using the PVSyst software, a comparative analysis of a grid-connected PV system under fixed, vertical single-axis tracking and double-axis tracking was carried out for Nepal's five climate zones under various climatic and geographic conditions. The annual energy output, performance ratio, LCOE, and payback period were used to generate a thorough technical and economic study. Conclusion: Of the chosen locations, Jumla has the largest annual generation, the lowest cost of energy, and the shortest payback period. Lumle and Kathmandu are the next most economically viable choices. Dharan and Nepalgunj, on the other hand, exhibit the poorest performance, with the lowest yearly generation, greatest energy cost, and longest payback period. Additionally, the double-axis tracking system closely matched the simulation findings when the results of the simulation were validated with analytical calculations. The overall findings indicate that the development of a mega-scale grid-connected PV plant is feasible at each of the chosen locations. Policymakers and investors would be helped by the findings presented in this study to identify appropriate location-based technologies for maximizing return on investment in large-scale projects in Nepal's grid-tied solar industry.

6. Recommendations

To further comprehend the system's functioning, experimental analysis taking whole year data into consideration needs to be performed in order to have a better understanding of the performance of the system. Structural analysis and actual wind load analysis either experimentally or simulation need to be done for the tracking system to verify the calculations. As per the result of this research, it is evident that the grid-connected system is economically viable. The solar-powered PV system should be taken into account by the government of Nepal from a wider angle. Solar PV plants with tracking systems have to be approved because they can produce more power on a small area of land in a small nation like Nepal.

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References

[1] Harry Wirth. Recent Facts about Photovoltaics in Germany. *Fraunhofer Institute for Solar Energy Systems ISE*, 1, 2021.

[2] Dagmar Henner. Renewables 2021- Global Status Report. *REN21*, 1, 2021.

[3] Photovoltaics Report. *Photovoltaics Report, Fraunhofer Institute for Solar Energy Systems ISE, Freiburg*, 1, 2020.

[4] R Eke and A Senturk. Performance comparison of a double-axis sun tracking versus fixed PV system. *Solar Energy*, 86(9):2665–2672, 2012.

[5] Solar Tracker. Solar tracker — Wikipedia, the free encyclopedia, 2022.

[6] Solar Tracker Market. Solar tracker market size, 2019. Solar Tracker Market Size, Share & Trends Analysis Report By Technology (Solar PV, Concentrated PV, Concentrated Solar Power), By Product (Single Axis, Dual Axis), By Application, By Region, And Segment Forecasts, 2019 - 2025.

[7] Andrew Blakers and Sunil Parsad Lohani. Solar energy: Nepal's most sustainable resource. *The Himalayan Times*, 2020.

[8] Krishna R Adhikari, Shekhar Gurung, and Binod K Bhattarai. Solar energy potential in nepal and global context. *Journal of the Institute of Engineering*, 9(1):95–106, 2013.

[9] Sudeep Ghimire and Zulker Naeen. Renewable energy: Huge potentials. *The Himalayan Times*, 2017.

[10] World Bank Group. Solar resource and photovoltaic potential of nepal. 2017.

[11] Ministry of Finance. Economic survey ministry of finance. 2021.

[12] IHA. Hydropower status report. 2021.

[13] Nepal Electricity Authority. *A Year in Review Fiscal Year 2020/21*.

[14] Nepal Electricity Authority. *A Year in Review Fiscal Year 2019/20*.

[15] Nepal Rastra Bank. *Monetary Policy of 2018/19*.

[16] Ranjan Parajuli, Poul Alberg Østergaard, Tommy Dalgaard, and Govind Raj Pokharel. Energy consumption projection of nepal: An econometric approach. *Renewable Energy*, 63:432–444, 2014.

[17] Meen B Poudyal Chhetri and Anil Shakya. Wind intensity measurement and wind loading codes in nepal.

[18] QCB Bearings. *QCB Slewing Drives Power*.

[19] Ramhari Poudyal, Pavel Loskot, and Ranjan Parajuli. Techno-economic feasibility analysis of a 3-kw pv system installation in nepal. *Renewables: Wind, Water, and Solar*, 8(1):1–18, 2021.

[20] Kamrul Islam Chowdhury, Md Alam, Promit Shams Bakshi, et al. Performance comparison between fixed panel, single-axis and dual-axis sun tracking solar panel system. 2017.