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# Performance Evaluation of 8.5 MW grid connected Solar PV Plant in Butwal, Nepal

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**Abstract**
The rising energy demand in Nepal has prompted the matter of energy security. Further, to maintain the energy mix it is essential to use alternative renewable resources. Grid connected megawatt scale PV systems possibly are the best alternatives. The Butwal solar project is the leading large Solar PV project built and operated by an independent power producer in Nepal. The growth of investment on such a large grid connected solar project will ultimately depend on its performance. The performance analysis of an 8.5 MW grid connected PV power plant installed at Butwal, Nepal is worked out. By analyzing the plant's first-year operational performance, it is found that final yield, reference yield, Capacity Utilization Ratio (CUF) and Performance Ratio (PR) varies from 2.33 to 3.80 kWh/kWp-day, 3.87 to 6.20 kWh/kWp-day, 9.7 to 15.8% and 54 to 77% respectively. The annual average final yield, CUF and PR are found to be 1140.4 kWh/kWp, 13%, 64.2% in close agreement to PVSYST estimated outcomes 1372 kWh/kWp, 15% and 72% respectively. The performance of the plant is compared with PV systems installed in various parts of the world and found comparable. Financial analysis shows that plant discounted payback period is 16.3 years with the proper return of NRs. 58.88 million in its useful life. The LCOE is found to be 6.7 NRs/kWh. Carbon emission balance analysis shows that 952 $tCO_2$ emissions are replaced in plant's useful life. The findings give insight into the solar power plant's long-term performance in Nepal's Terai area under real working circumstances. The need for regular maintenance against array capture loss, making the grid more reliable and the use of MPP having a large voltage range in the inverter is highlighted to maximize energy generation and export to the grid. Additional, supplement research studies are also recommended.

**Keywords**
Grid-connected PV system, Performance parameters, PVSYST, Techno-economical analysis

## 1. Introduction

The conventional sources of energy, fossil fuel, are depleting rapidly as well as seriously impacting on environment. This reason impulses to focus on other alternative source of energy. One of the non-conventional source which does not produce harmful gases for power generation is Photovoltaic system [1].

Nepal Government's policy, National Energy Crisis Mitigation and Power Development Decade Concept Paper and Action Plan 2072 BS, had aimed to energy mix by connecting alternative renewable electrical energy to the national grid with an upper limit of 10% of the total connected capacity. Accordance to this policy to maintain the energy mix, in June 2016 the Nepal Electricity Authority (NEA) had requested the proposal, looking for bids from concerned parties to install solar PV plants and supply electricity to the national grid. In the bidding for 63 MW capacity projects, 18 projects having a total capacity of 61 MW were proposed. Out of them, the tender for the 8.5 MW Butwal grid connected solar power project had been taken by Ridi Hydropower Development Company Limited (RHDL). The company completed the work within a year regardless of the COVID-19 pandemic and the subsequent lockdown and started generating power from October 2020 [2].

Nepal benefits from enormously fortunate climatic conditions for the use of PV power generation. A south oriented 30° fix tilted photovoltaic installation can produce 1700 kWh/kWp/Year while it can produce 2300kWh/kWp/Year with inclusion of a two-axes sun tracker [3]. There are many performance evaluation studies of grid connected PV system globally as referenced by [1, 4, 5, 6, 7, 8, 9]. In those literature, researchers have revealed the applicability of simulating software tools in modeling a PV plant along with evaluating the performance feasibility.The performance results vary based on various factors like solar irradiation, sun tracker system, temperature, shading or contamination of the PV modules, measurement period, system efficiency and losses [10].

The performance ratio is one of the vital parameters for evaluating the performance of a photovoltaic system. According to DoED, till January 2022 many numbers of license has been issued for solar projects, where for construction 19 projects had a total capacity of 118 MW and for survey 26 projects had a total capacity of 624 MW. Also, NEA shows that the total installed capacity of grid connected solar PV is 39.08 MW while other projects of a total capacity of 65 MW that have signed PPA are in different stages of development. As Butwal solar project is one of the leading large projects built and operate by independent power producer. The growth of investment on such large grid connected solar project will ultimately depends on its performance. Hence the designed system and performance parameters are need to be properly analyzed and studied so that it provides some guideline for upcoming future installations.

The major scope of this research is analysis of existing plant by simulating it on PVSYST program and compare the actual performance data with that simulated results of PVSYST. Also, Financial analysis is done to find project basic outcomes like NPV, IRR, LCOE and sensitive analysis is performed for finding the most sensitive parameter affecting financial performance.

## 2. Details of Butwal Solar PV System

### 2.1 Site Information

Butwal Solar Project is located at Lumbini province Tilottama-6, Nurserygram, Butwal Nepal. Butwal is one of the major developing cities of Nepal which lies in the Terai plain area. Its elevation level is 150 masl. The climate in this region usually reaches scorching hot in summer whereas foggy cold in winter. The Sailent Features of the project is shown in table 1.

**Table 1:** Sailent Features of the project

| | |
|---|---|
| Provience | Lumbini |
| District | Rupandehi |
| Municipality | Tilottama-6 |
| Latitude | 27°37′42″N-27°38′08″N |
| Longitude | 83°27′05″E-83°27′23″E |
| Average Insolation | 4.9 kWh/m$^2$/day |
| Average Temperature | 25°C |
| Relative Humidity | 62 % |
| Average Wind Speed | 0.7 m/s |
| Installed Capacity | 10612.8 kWp [DC]<br>8500 kVA [AC] |
| Annual Energy (PPA) | 1,45,10,584 KWh |
| Transmission line | 5.6Km |
| Grid frequency/voltage | 50 Hz / 33kV |
| Project Cost | NRs. 67.5 Crores |
| Construction period | 2019/20 (AD) |

### 2.2 SINGLE LINE DIAGRAM

The overall plant single line Diagram (SLD) is shown in figure 1 where ten similar inverters were fed from different PV array. The three winding transformer having two input winding is connected with five inverters in each winding. Various protective control relay, switchgear is used in order to protect transformer and to ensure proper quality power supply.

### 2.3 PV Module

The solar module used were Polycrystalline Waaree Module, each rated 330 Wp. There are 32,160 identical solar modules used, thus comprising a system of total capacity 10.61 MWp. PV array were tilted at angle of 23° facing south. The detail technical description is shown in table 2.

**Table 2:** Solar module specification

| | |
|---|---|
| Manufacturer/Technology | Waaree/pc-si |
| Rated Capacity | 330 Wp |
| Rated Voltage (Vmpp) | 37.13 V |
| Rated Current (Impp) | 8.89 A |
| Open circuit Voltage (Voc) | 45.95 V |
| Short circuit current (Isc) | 9.57 A |
| Module Size (mm) | 1960×990×40 |
| Efficiency | 17.01 % |
| NOCT | 46°C (±2°C) |
| Temp. coeff. of Pmpp | -0.3859 %/°C |
| Temp. coeff. of Voc | -0.2775 %/°C |
| Temp. coeff. of Isc | 0.0154 %/°C |

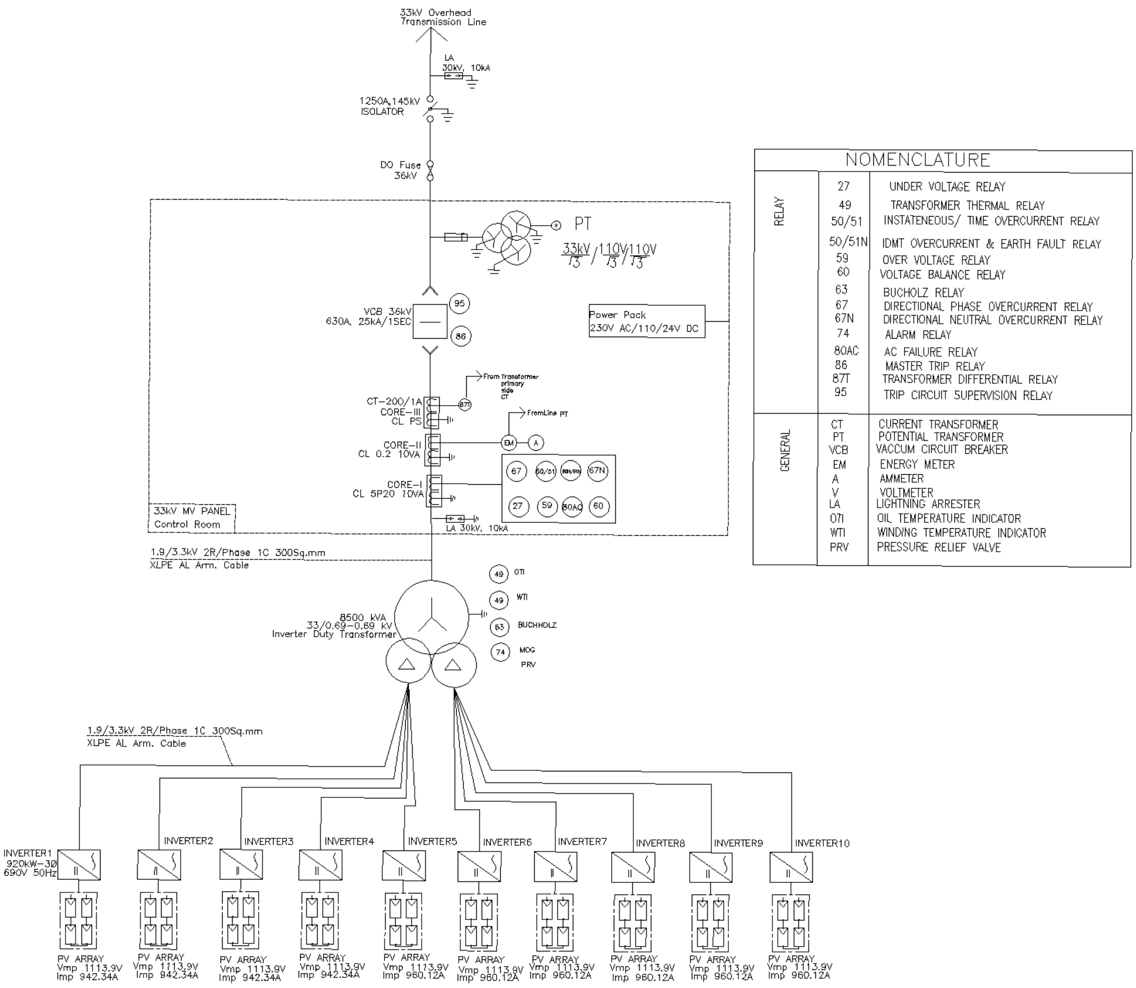


**Figure 1:** Single line diagram

## 2.4 Inverter

Ten numbers of similar inverter each having maximum output capacity of 920 kW were used. Table 3 shows the detail specification of the inverter. All inverters utilizes its four Maximum Power Point Tracker (MPPT) input units where 26 to 28 strings combination is fed to each input. 30 modules were connected in series to form a string.

**Table 3:** Inverter specification

| | |
|---|---|
| Manufacturer | TMEIC |
| Rated Input Power (DC) | 939 KWp |
| MPP Voltage Range | 1005 V to 1300V |
| Max. Input current | 934 A |
| Rated Output Power (AC) | 920 kW @ 25°C<br>840 kW @ 50°C |
| Nominal AC voltage | 690V (3-Ph) |
| Rated Output Current | 770 A |
| Efficiency | 98% |

## 2.5 Transformer

In this plant 3 phase Inverter duty transformer having No Load Tap Changer (NLTC) features is used. The use of inverter duty transformer makes the solar plant system reliable and durable as inverter windings are specially designed to withstand voltages excursions that arise due to inverter operation. Other technical specification of transformer is given in table 4.

**Table 4:** Transformer specification

| | |
|---|---|
| Manufacturer | Raychem RPG |
| Capacity | 8500 KVA |
| Voltage | 33/2×0.69 kV |
| Current | 148.71/2×3556.14 A |
| Vector group | YNd11d11 |
| Impedance (HV-LV) | 6.58% |
| Tap changer | ±7.5% in step of 2.5% |
| Type of Cooling | Oil Natural Air Natural |

## 3. Methodology

The research began with a literature review of grid connected solar photovoltaic systems. This was followed by collection of data, simulation in PVSYST and comparison of actual and estimated results. Similar framework was used for validating the simulated and real-time monitored PV performance in various literature [1, 11, 8].

### 3.1 Performance Analysis

The IEC standard 61724 defines the solar PV performance parameters with respects to the energy production, irradiation and various losses on the system, that can be used to define the overall photovoltaic system performance. The main parameters of interest for this analysis are the reference yield, final yield, capacity utilization factor and performance ratio [12].

#### 3.1.1 Reference Yield

The reference yield $(Y_r)$ is the total in-plane solar insolation H (kWh/m$^2$) divided by the PV's reference irradiance G (1kW/m$^2$). It represents an equivalent number of hours at the reference irradiance [8].

$$Y_r = \frac{H(kWh/m^2)}{G(1kW/m^2)} \tag{1}$$

#### 3.1.2 Final Yield

The final PV system yield $(Y_f)$ is the net A.C. energy output E (kWh) for a define period divided by the nameplate DC power P (kWp) of the installed PV array. It represents the number of hours that the PV array would need to operate at its rated power to provide the same energy. The units are hours or kWh/kWp [1].

$$Y_f = \frac{E(kWh)}{P(kW_p)} \tag{2}$$

#### 3.1.3 Performance Ratio

The performance ratio PR is the ratio of final yield to reference yield. It quantifies the overall effect of losses on the rated output due to: incomplete use of irradiance by reflection from the module front surface; PV module temperature soiling or snow; inverter inefficiency, wiring, mismatch, and other losses when converting from DC to AC power; system down-time and component failures [8].

$$PR = \frac{Y_f}{Y_r} \tag{3}$$

#### 3.1.4 Capacity Utilization Factor

CUF is the ratio of the actual AC energy output from a solar plant over the year to the maximum possible output from it for a year under ideal conditions . Capacity utilization factor is usually expressed in percentage and normally lies between 18 to 22%. It depends on the location of the PV system [8].

$$Y_F = \frac{E_{annual}}{P(kW_p) \times 8760} \tag{4}$$

#### 3.1.5 Array Capture and System Losses

Array capture losses $(L_c)$ are due to the losses on PV array. While system losses $(L_s)$ are due to DC into AC conversion by inverter including system down-time [7]. These losses are given as

$$\begin{aligned} L_c &= Y_r - Y_a \\ L_s &= Y_a - Y_f \end{aligned} \tag{5}$$

Where $Y_a$ is array yield.

### 3.2 Financial Analysis

The following measures of worth are detremined for the aim of assessing the cost-effectiveness of the Butwal solar plant. These measures of worth account for the time value of money[13].

#### 3.2.1 Net Present Value

Net present value (NPV) is the difference between the present value of cash outflows and cash inflows over a period of time. NPV is used in investment planning and capital budgeting to examine the viability of a projected outlay [14, 5].

$$NPV = \sum_{t=1}^{n} \frac{B_t}{(1+i)^t} \tag{6}$$

Where, $B_t$ is Net cash inflow during a single period t, i is Discount rate and t is the Number of times periods

#### 3.2.2 Internal Rate of Return

The internal rate of return (IRR) is the discount rate which gives NPV of zero for estimated future series of cash flows [14]. .

$$\sum_{t=1}^{n} \frac{B_t}{(1+IRR)^t} - B_o = 0 \tag{7}$$

Where, $B_o$ is initial investment costs.

### 3.2.3 Payback Period

Payback Period is an estimated time for the revenue saving to completely recover the initial investment plus a stated rate of return. If recover of only the initial investment is considered then it is called Simple Payback Period (SPP) [13].

$$SPP = \frac{B_o}{B_t} \tag{8}$$

### 3.2.4 Debt-Service Coverage Ratio

The debt-service coverage ratio (DSCR) is a measurement of a firm's available cash flow to pay current debt obligations.It indicates whether a company has enough income to pay its debts [13].

$$DSCR = \frac{Net\ Operating\ Income}{Current\ Debt\ obligation} \tag{9}$$

A DSCR below 1 could indicate that the firm is under financial difficulties whereas greater than 1.25 is often considered strong.

### 3.2.5 Levelized cost of energy

The levelized cost of energy (LCOE) is ratio of NPV of cost to NPV of energy produced over lifetime of plant. Similar to using NPV, the LCOE can be used to determine whether a project will be a worthwhile venture[14].

$$LCOE = \frac{\sum_{t=1}^{n} \frac{P_t+M_t+F_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}} \tag{10}$$

Where, $P_t$ is capital investments made in year t, $M_t$ is operating and maintenance costs for year t, $F_t$ is fuel costs for year t, $E_t$ is amount of electricity generated in year t and n is useful life of plant.

## 4. Results and Discussions

### 4.1 Estimated Energy and performance

Table 4.1 shows that specific yield varies from 89.80 (January) to 128.34 (October) with yearly average of 1372.31 kWh/kWp. Similarly, performance ratio varies from 0.79 (January) to 0.66 (May). The yearly average capacity utilization factor is 15.13 %. It varies from 11.87 % to 19.95 %.

**Table 5:** Estimated monthly performance factors

| Month | $T_{amb}$ (°C) | GlobInc kWh/m$^2$ | $E_{grid}$ MWh | $Y_f$ (h) | PR (%) | CUF (%) |
|---|---|---|---|---|---|---|
| Jan | 15 | 112 | 937 | 90 | 79 | 11.9 |
| Feb | 19 | 146 | 1091 | 116 | 70 | 15.3 |
| Mar | 24 | 197 | 1575 | 151 | 75 | 20.0 |
| Apr | 29 | 191 | 1447 | 138 | 71 | 18.9 |
| May | 31 | 178 | 1241 | 127 | 66 | 15.7 |
| Jun | 31 | 150 | 1092 | 105 | 69 | 14.3 |
| Jul | 30 | 136 | 1002 | 96 | 70 | 12.7 |
| Aug | 29 | 143 | 1078 | 103 | 71 | 13.7 |
| Sep | 29 | 150 | 1141 | 109 | 72 | 14.9 |
| Oct | 26 | 169 | 1344 | 128 | 75 | 17.0 |
| Nov | 21 | 144 | 1175 | 112 | 77 | 15.4 |
| Dec | 17 | 122 | 942 | 97 | 73 | 11.9 |
| Yearly | 25 | 1838 | 14065 | 1372 | 72 | 15.1 |

Table 5 selected data is shown figure 2 to understand the consequence of temperature and irradiance on power output of the system. Even if there is good amount of radiation the power output decreases up to some range as a result of rise on temperature.

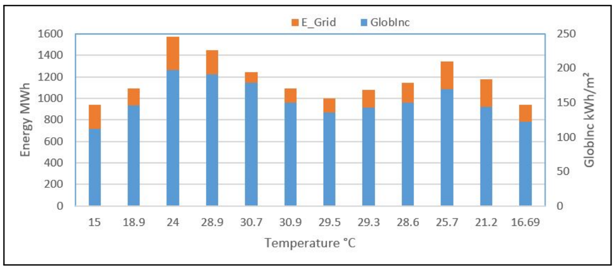


**Figure 2:** Monthly Insolation vs. $E_{grid}$ vs. Temp

### 4.2 Loss Diagram

Sankey diagrams are a type of flow diagram in which the width of the arrows is are linearly proportional to energy production, utilization and loss. As shown in figure 3 energy input of Global Tilted Irradiation (GTI) of 1838 kWh/$m^2$ produce energy output of 1738 kWh/$m^2$ considering soiling, reflectivity and spectral correction. Due of conversion loss from solar radiation to electrical energy and technical availability of grid the energy output becomes 14,064 MWh. The majority of losses are due to soiling factor, irradiance level, temperature and inverter voltage threshold. It is found that about 3.06% loss occurs due to inverter voltage threshold. The shading losses are neglected due to the free orientation of module structures.

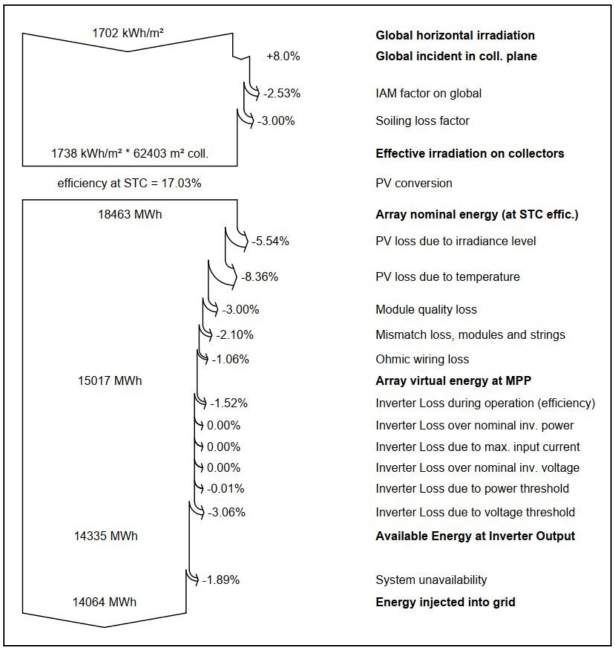


**Figure 3:** Sankey diagram over a year of operation

## 4.3 Carbon Emission Balance

The lifecycle emissions of the plant and its detail are shown in table 6. From the simulation, it is found that the total energy injected into the grid is 317,292,442.74 kWh in 25 years of operation. The total $CO_2$ emissions produced are 18,186 tons including production, operation, maintenance and disposal of the plant's components. The replaced emissions based on energy generation are 952 tons because Nepal's grid-connected energy source emissions are only 3 $gCO_2$/kWh as the main sources are hydropower [15].

**Table 6:** Lifecycle Carbon emission balance

| Generated | LCE | Quantity | Subtotal KgCO2 |
|---|---|---|---|
| Modules | 1713 $KgCO_2/kWp$ | 10613 | (18180069) |
| Supports | 0.02 $KgCO_2/kg$ | 321600 | (6432) |
| Inverters | 1.98 $KgCO_2/units$ | 10 | (19.8) |
| **Total Generated emissions** | | | **(18186520)** |
| **Replaced** | 3 $gCO_2/kWh$ | 317292443 | **951877** |
| **Net emission balance** | | | **(17234643)** |

## 4.4 Actual Energy Production and Performance

The plant starts test generation from mid of Nepali month Asoj 2078 BS. So, from month of Kartik year 2077 BS to end of Asoj 2078 BS, the performance indicator table 7 is developed. It shows that plant is generating less than that of simulated and contract energy except first month of operation "Kartik". The average annual PR, CUF, Specific energy is found to be 64 %, 13 % and 1140 kWh/kWp respectively.

**Table 7:** Actual monthly performance factors

| Month | GlobInc (kWh/m²) | $E_{grid}$ (Mwh) | $Y_f$ (h) | PR (%) | CUF (%) |
|---|---|---|---|---|---|
| Kartik | 134 | 1183 | 111 | 83 | 15.5 |
| Mangsir | 119 | 887 | 84 | 70 | 12.0 |
| Poush | 116 | 741 | 70 | 60 | 9.7 |
| Magh | 121 | 754 | 71 | 59 | 10.2 |
| Phalgun | 157 | 1033 | 97 | 62 | 13.5 |
| Chaitra | 183 | 1210 | 114 | 62 | 15.8 |
| Baisakh | 192 | 1226 | 115 | 60 | 15.5 |
| Jestha | 179 | 1078 | 102 | 57 | 13.7 |
| Ashadh | 163 | 929 | 87 | 54 | 11.8 |
| Shrawan | 144 | 1044 | 98 | 68 | 12.8 |
| Bhadra | 140 | 937 | 88 | 63 | 11.9 |
| Ashwin | 142 | 1081 | 102 | 72 | 13.7 |
| **Annual** | 1790 | 12103 | 1140 | 64 | 13.0 |
| **PVSYST** | 1838 | 14065 | 1372 | 72 | 15.1 |
| **Error (%)** | 2.68 | 16.21 | 20 | 12.1 | 15.4 |

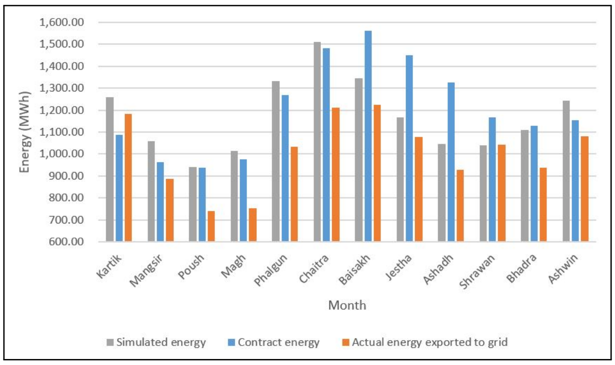


**Figure 4:** comparisons of simulated, contract and actual energy exported to grid

The figure 4 shows the contract energy between NEA and Butwal solar Power plant is nearly equal to that of estimated value after simulation. Some difference as seen may be due to different metrological data source and loss calculation under study. The estimated energy delivered to grid ($E_{grid}$) using PVSYST software are in near pact with the contract energy with difference of 3.07 % in a year value. It can be seen that contract energy for the month of Baisakh, Jestha and Asar was assumed relatively high than the actual generation and PVSYST estimation. The actual generation for first year of operation is found to be 13.95 % and 16.21 % less than to those of estimated and contract values respectively although the difference in irradiation vaue is only 2.68 %. This indicates that the system needs to reduce avoidable losses in order to benefit from maximum possible energy generation.

## 4.5 Financial outcome

The plant's financial related input parameter and key result obtained from MS Excel computation is shown in table 8 and 9 respectively.

**Table 8:** Financial key input

| Financial Parameter | | Ref. |
|---|---|---|
| Installed capacity (kWp) | 10,612 | [16] |
| Annual contract energy (kWh) | 14,510,583 | [17] |
| Annual energy degradation | 0.80% | [18] |
| Project base cost (million NRs.) | 675 | [16] |
| Project life time (years) | 25 | [17] |
| PPA rate (NRs.) | 7.3 | [17] |
| O/M cost (NRs. per KWp/year) | 442.5 | [19] |
| Annual escalation on O/M | 5.10% | [20] |
| Interest rate | 11.98% | [21] |
| Tenure (years) | 7 | [22] |
| Debt | 70.00% | [2] |
| Debt amount (million NRs.) | 472.5 | - |
| Corporate income tax | 20.00% | [23] |
| Cost of equity | 17.00% | [24] |
| Equity | 30.00% | [2] |
| Equity amount (million NRs.) | 202.5 | - |
| Discount rate (WACC) | 11.81% | - |

**Table 9:** Financial key results

| | |
|---|---|
| Project IRR | 13.28% |
| Project NPV (million NRs.) | 58.88 |
| Equity IRR | 22.17% |
| NPV of equity (million NRs.) | 209.36 |
| Simple Payback (years) | 6.9 |
| Discounted payback (years) | 16.3 |
| Minimum DSCR | 1.37 |
| Average DSCR | 1.52 |
| LCOE (NRs./kWh) | 6.7 |

The positive values of NPV shows that the Butwal solar PV plant's outcome is financially beneficial with IRR of 13.28 % and discounted payback period is 16.3 years. LCOE value is found to be 6.7 Rs/kWh which is slightly less than tariff rate 7.3 Rs/kWh.

Since there are number of uncertainties in the feasibility study about future outcome of the project so, risk or sensitivity analysis must be done. The tornado diagram figure 5 below shows that annual energy generation is more sensitive for NPV of the project while degradation and operating maintenance cost nearly equal variation when changing these input parameter value by ±20 %. As the revenue is a product of energy generation and tariff rate, the variation of tariff rate have the same effect on NPV as that of energy generation. NPV is negative even if annual energy supplied to grid quoted in contract value decreases by 10 %. So, the plant engineers and energy company officials should focus on maintaining the plant in order to decrease the losses in generation and avoid financial loss from this project.

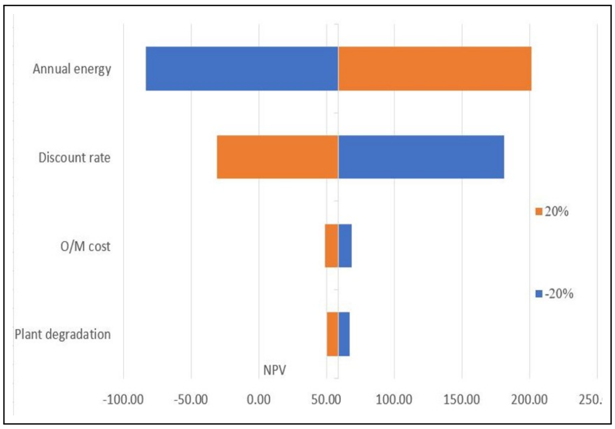


**Figure 5:** Sensitive analysis of NPV

Since the annual energy delivered from the plant to the grid depends on the average annual Global Horizontal Irradiance (GHI), table 10 shows the correspondence energy variation when the GHI is varied in the range of 80% to 119% of the base value of 1702 kWh/m².

**Table 10:** Variation in GHI to evaluate $E_{grid}$

| GHI (kWh/m²) | 1362 | 1532 | 1702 | 1872 | 2026 |
|---|---|---|---|---|---|
| $E_{grid}$ (MWh) | 10606 | 12360 | 14065 | 15708 | 17110 |

**Table 11:** Performance Comparison with existing literature

| Location | KWp | Module | Monitor Duration | Yr (kWh/kWp/day) | Ya | Yf | CUF (%) | PR (%) | Reference |
|---|---|---|---|---|---|---|---|---|---|
| Butwal, Nepal | 10612 | pc-si | Oct 2020-Sept 2021 | 4.9 | 3.22 | 3.1 | 13.00 | 64.20 | This study |
| serpong, Indonesia | 10.6 | pc-si | Jul 2019-Feb 2020 | 4.12 | 3.49 | 3.38 | 14.07 | 82.40 | [4] |
| Andra pradesh, India | 1000 | pc-si | Oct 2018-Sept 2019 | - | - | 4.61 | 20.80 | 88.00 | [1] |
| Morocco | 2.04 | mc-si | 2015 | - | - | 5.17 | 21.56 | 80.66 | [5] |
| | 2.04 | pc-si | | - | - | 5.26 | 21.93 | 82.00 | |
| Ramagundam, India | 10000 | pc-si | Apr 2014-Mar 2015 | 4.97 | - | 4.45 | 17.68 | 76.20 | [8] |
| Khatkar-Kalan, India | 190 | pc-si | 2011 | 2.91 | - | 2.15 | 9.27 | 74.00 | [9] |
| Dublin, Ireland | 1.72 | mc-si | Nov 2008-Oct 2009 | 2.85 | 2.62 | 2.41 | 10.10 | 81.50 | [25] |

## 5. Conclusions and Recommendations

This study provides a first-year operation performance including estimated financial and technical outcome of megawatt-scale grid connected PV system in Nepal. The actual generation for first installation month “Kartik” seems reasonably high due to newly solar module. As the month passes due to soiling loss the energy degrades. In the winter months like Poush, Magh etc. due to less sunshine hours and foggy weather for several days’ effects on PV production. As far as the comparison of actual energy injected to the grid with PVSYST results, the plant is operating nearer to the predicted generation of energy modelling software.

For comparison purpose few literature on similar field were considered as shown in table 11. The final yield normalizes the energy produced with respect to the system size; consequently, it is a convenient way to compare the energy produced by PV systems of differing size. In this study the annual average daily final yield of the PV system was 3.1 kWh/kWp/day which was higher than those stated in Khatkar-Kalan, India Dublin, Ireland. It is comparable to results from serpong, Indonesia but lesser than the reported yields in Morocco, Andra Pradesh and Ramagundam - India.

The loss value $(L_c)$ of 1.69 kWh/kWp/day reveals that major loss on array capture. Although the manual cleaning of PV array is done on certain intervals of days, as the plant lies on developing city of Nepal, the dust accommodation take place within a day. So, it is recommended to increase the periodic cleaning of the module surface. Simulation loss diagram result indicates that about 3% which account for about 450 MWh of annual energy is lost due to inverter voltage threshold. This loss could have been omitted if the inverter had a wider MPP voltage range, especially in lower levels up to 900V was used. The plant has been exporting energy to the grid around 96.43% of available percentage, it shows that grid unavailability is also contributing for system loss. NEA should maintain the high reliability of its grid network to full utilization of grid connected solar PV systems. Also, to fix the contract energy during PPA signing with solar PV projects, it is recommended to use simulating software like PVSYST to evaluate the corresponding monthly energy generation throughout the year rather than using a simple calculation. PVSYST accounts for a non-linear loss like loss due to irradiance level effectively which is difficult to estimate in a simple calculation.

Financial analysis shows that plant would give a return of 13.28% with an NPV of NRs. 58.88 million. Energy generation is the most sensitive parameter affecting the financial outcome. Besides generated energy revenue the project is also utilizing fertile land under PV panel by farming which will make an additional benefit. Since a carbon emission balance study reveals that around 952 $tCO_2$ wii be replaced over the project’s lifetime, it also supports the government’s carbon trading.

The result data and operating experience of this PV system can be applied for future large-scale projects; for example, during feasibility study of solar PV project in Nepal Terai region using PVSYST, it can be assumed that the actual annual energy generation could be below about 14% than that of the simulated result. Installation of large-scale solar PV should consider proper land use by an alternative method like turmeric and kimchi farming done here in this project to earn additional benefits besides energy revenue.

Despite the study’s thorough nature, it’s vital to bring out several shortcomings in the analysis that could serve as a future research topic. A detailed study can be undertaken to analyze the trend of output by evaluating the Performance ratio over the years. Further detailed analysis can be done to evaluate the effect of ambient temperature, soiling, annual degradation rates and other conversion loss on the total performance of the solar PV power plants. Such supplementary data will be used as a reference for future investigations involving performance modelling under comparable climatic conditions.

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