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Performance analysis of a 100 kWp grid connected Solar Photovoltaic Power Plant in Kharipati, Bhaktapur, Nepal

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Abstract
The performance analysis of a 100 kWp grid connected solar photovoltaic power plant installed at Nepal Electricity Authority Training Center, Kharipati, Bhaktapur, Nepal (27.68 Latitude and 85.46 Longitude) was carried out. The system was monitored from January 2016 to December 2016. In the measured period, the annual energy yield was 88.41 MWh and average solar insolation of the location for 2016 was found 4.14 kWh/m2/day. The monthly final yield, reference yield and performance ratio have been found to vary from 43.85 to 105.27 kWh/kWp, 103.3 to 156.2 kWh/kWp and 34% to 70% respectively. The annual average performance ratio, capacity factor, inverter efficiency, array efficiency and system efficiency were found to be 54%, 10.09%, 97%, 8.09% and 7.85% respectively. The study shows that energy generated was maximum 10.53 MWh during November and minimum 4.39 MWh during January. The study helps engineers and researchers in this area to understand grid connected PV system and encourage them to set up similar PV power plants.

Keywords
Photovoltaic Performance Analysis – Grid connected Solar – Performance Ratio – Capacity factor

1. Introduction

Energy is one of main ingredients for the development and maintenance of a modern society with benefits of its socio-economic and technological advancements. Providing energy for homes and buildings, agriculture, transportation, services, and industries in a sustainable way and at the same time guaranteeing resources for the future generations is the ultimate challenge for the humanity. Among the various forms of renewable energies such as wind energy, bio energy and others, photovoltaic energy occupies a prominent position due to many peculiarities. Economic incentives, reduction in cost, and the fast technological developments allow the use of grid connected photovoltaic plants in a simple, efficient and profitable way. The photovoltaic (PV) energy assumes, therefore, an increasing role within the spectra of the energy sources, especially for its simplicity of installation and integration in building architecture.

Nepal benefits from extremely favorable climatic conditions with excellent level of solar irradiance for the use of Photovoltaic technology with grid connected plants. The climatic conditions of Nepal are extremely favorable for the use of solar energy systems in comparison with central European conditions (Chianese et al., 2009). Grid connected PV experience in Nepal is still limited to a handful of small installations such as at NEA office, Min Bhawan, NEA Training Center, Kharipati, CES Pulchowk Campus, RIDS-Nepal Office, Imadol and KUKL Dhobighat, Lalitpur. So it is important for the country to be prepared and to accumulate experience with grid connected PV in order to be able to make the most of distributed benefits.

The Grid connected PV system connects with existing national grid network and supply power to the existing load. This system operates only when existing national grid network is in normal operation. This is to avoid any unexpected accidents due to possible power injection to the existing grid when it is not operating (Luque et al., 2003). Such PV systems are required to introduce solar energy into urban areas. Grid connected PV systems can be installed on the facades and rooftops of buildings, on the shades of parking lots and can also be installed as power plants that aim to inject all their produced power into the grid. The grid connected PV system is mainly composed of a matrix of PV arrays, which converts the sunlight to DC power and a Power Conditioning Unit (PCU) that converts the DC power to AC power and injects it into the grid. In some cases, storage devices are used to improve the availability of the power generated by the PV system.

Performance assessment of PV systems is the best way to determine the potential for PV power production in an area. Usually the performance of photovoltaic modules refers to Standard Test Condition (STC), which is not always representative for the real module operation. The energy produced by a grid-connected photovoltaic system depends on (Sidrach-de-Cardona and Lopez, 1999): Climatic factors (incident irradiation and module working temperature); inverter characteristics (yield, working point and operation threshold, defined as the minimum required power to connect the inverter to the grid) ; the coupling system to the grid, which depends on the characteristics of the energy produced by the inverter and on grid stability and availability; bird's droppings; Dirt and Dust; Load Shedding and continuous use. Dust accumulation is found to act as major detrimental agent to reduce PV module output by attenuating the transmittance loss (Paudyal et al., 2017).

There are many performance evaluation studies of grid connected PV systems globally as referenced by Sharma and Chandel (2013), Bhattarai (2013), Milosavljevic et al. (2014), Díez-Mediavilla et al. (2012), Kumar and Nagarajan (2016), Kumar et al. (2014), Dabou et al. (2016), Sharma and Goel (2017), to name a few. The performance assessment of a grid connected PV system include parameters calculation such as: annual energy generated, reference yield, array yield, final yield, array capture losses, system losses and cell temperature losses, PV module efficiency, system efficiency, inverter efficiency, performance ratio, and capacity factor. Results obtained will provide useful information to policy makers and interested individual and organization about actual performance of grid connected PV system in a region or country (Carmo de Lima et al., 2015).

The main objective of this article is to evaluate the performance of a 100 kWp grid connected photovoltaic system installed at Nepal Electricity Authority Training Center, Kharipati, Bhaktapur, Nepal.

2. Details of Grid Connected PV System

2.1 Site Information

The 100kWp grid connected PV System under research is located at Nepal Electricity Authority (NEA) training Center, Kharipati, Bhaktapur District, Bagmati Zone, Nepal. The geographical location of the site is 27.68 (27^o 40' 59" N) Latitude and 85.46 (85^o 27' 31" E) Longitude (Figure 1).

Figure 1: Site Map (Source: Google Earth)

2.2 Mounting Structure of PV modules

The modules are erected at the ground near by the office. The tilt angle is 25 degree. The schematic of the panel mounted structure is as shown in Figure 2.

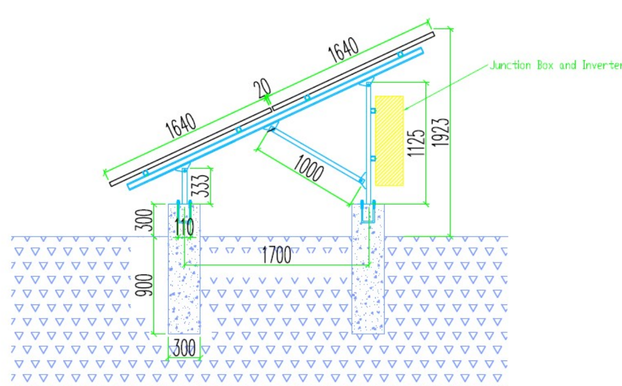

Figure 2: Mounting structure of PV panels

2.3 Layout of the PV system

The general structural layout of the panels on the ground and photograph of the installation is shown in Figure 3 and Figure 4 respectively. In order to ensure the installed capacity, the modules are vertically spread two rows.

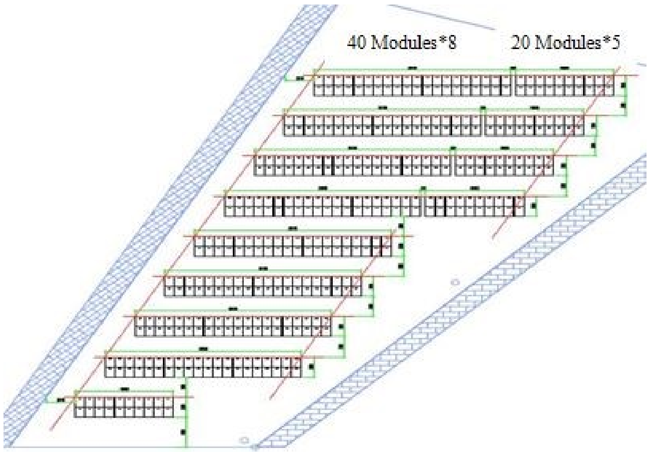

Figure 3: Layout of the PV system

Figure 4: PV System Installation

2.4 Single line diagram

The 100 kWp grid connected PV system consists of 420 polycrystalline silicon solar modules grouped into twenty one strings with each string containing 20 modules in series. The output of the strings is pooled in the array Junction Box through 4 mm^2 photovoltaic DC cable. The output from the Junction Box is fed to the grid tied Inverter. Four 2 MPPT 280-950 V, grid connected inverter is used as power conditioning units. Three inverters have 5 strings each and the other one has 6 strings connected to it.

The 30 kW Sun Grow (SG30KTL-M) grid connected inverter consisting of filters, maximum power point tracking (MPPT) system, inverter and control units is used to convert the PV power to three phase four wire, 400$\pm$ 5% V, 50$\pm$ 3% Hz ac power and to synchronize it with the nearby grid. DC and AC distribution cabinets contain protective components for safety of the system. A single line diagram of the grid connected PV system under research is shown in Figure 5.

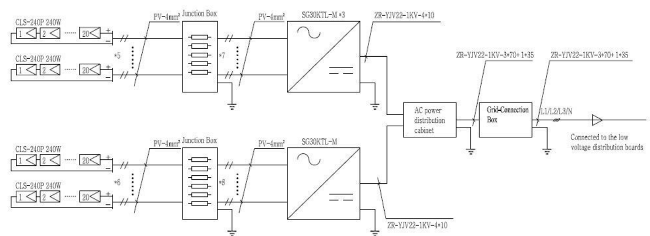

Figure 5: Single line diagram

2.5 Solar PV Modules

High Efficiency Solar module (CLS-240P type) material is Polycrystalline silicon solar cells. The specifications of solar PV module under Standard Test Condition (STC): Air Mass = 1.5, Solar irradiation = 1000 W/m^2 and module temperature of 25^{o}C, conforming to IEC 61215 are given in Table 1.

Table 1: PV module (CLS-240P) specification

Description	Value
Type	Poly Crystalline
Maximum Power (Pmax)	240Wp
Production Tolerance	0/+5 W
Open Circuit Voltage (Voc)	37.20V
Max. Power Voltage (Vm)	29.70V
Short Circuit Current (Isc)	8.64A
Max. Power Current (Im)	8.08A
Fuse Rating	10A
Module Efficiency	14.7%

The capacity of each solar PV module used is 240 Wp, which consists of 60 solar cells each of 156mm*156mm dimension. The modules are manufactured in China by

Chinalight Solar Co. Ltd and have excellent low light performance.

2.6 Power Conditioning Unit

The Power conditioning unit (PCU) under consideration is four 2 MPPT 280-950 V Sun Grow SG30KTL-M PV grid connected three phase transformer less string Inverters. Three Inverters each have 5 strings with 20 modules in series and the other one inverter has 6 strings with 20 modules in series. The total strings are twenty one and the total PV modules are 420 of 240 Wp each in the system. It is a crucial unit between the PV strings and utility grid in the grid connected PV System. It is dedicated to converting direct current power generated by the PV modules into alternating current, conforms to parameters of local utility grid and feeds it into the utility grid. The Inverters used in this system are manufactured in China by Sungrow Power Supply Co. Ltd. Figure 6 shows the circuit diagram of the SUNGROW Grid Connected Inverter.

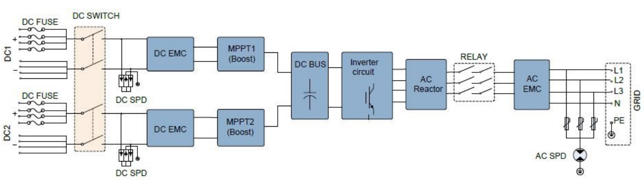

Figure 6: Circuit diagram of SG30KTL-M PV grid connected inverter

2.7 PV System Monitoring and Display Unit

Data logging and monitoring system is incorporated in the system to monitor the performance of the grid connected PV system throughout the year by providing real time data of PV and grid parameters. Standard RS485 interface for connecting the PV system into the Monitoring Device is included in the Inverter. The software used to monitor and display the different parameters of the 100 kW grid connected PV system is SolarInfo Insight which is manufactured in China by Sungrow Power Supply Co. Ltd.

2.8 Environment Monitoring Device

The device consists of Wind Speed Sensor (WSS), Wind Direction Sensor (WDS), Solar Radiation Sensor (SRS), Ambient Temperature Sensor (ATS), Solar Cell Temperature Sensor (SCTS), Main Control Box (MCB) and support brackets. It is generally applicable to measure wind speed, wind direction, solar panel radiation, ambient temperature, and solar cell temperature. The used device in this system is SolarInfo EM Device SSYW-01 type (Serial No A1403280192) made in China by Sungrow Power Supply Co. Ltd. The serial RS485 interface can be connected to the monitoring system, in order to acquire real-time data.

3. Methodology

The project began with a literature review of grid connected solar photovoltaic systems. This was followed by a continuous field visit to obtain the real time data related to parameters of meteorology, PV system and Grid. The parameters include:

- Solar irradiance in the plane of the array (W/m^2)
- Ambient Temperature
- PV array voltage (DC voltage)
- PV array current (DC ampere)
- Power output of PV array (DC watt)
- Tilt Angle
- Azimuth Angle
- Grid voltage (AC voltage)
- Grid current (AC ampere)
- Power input to grid (AC watt)
- Energy to grid (E_{AC})

The grid connected PV plant was fully monitored to assess its performance as per IEC standard 61724. In order to analyze the performance of a grid connected PV system the following performance parameters developed by International Energy Agency (IEA) Photovoltaic Power Systems Program were determined.

3.1 Total Energy Generated by the PV system

The total daily $(E_{AC,d})$ and monthly $(E_{AC,m})$ energy generated by the PV system is given as:

$$(E_{AC,d}) = \sum_{n=1}^{24} (E_{AC,t}), (E_{AC,m}) = \sum_{n=1}^{N} (E_{AC,d})$$

Where, N is the number of days in the month, $E_{AC,t}$ is the instantaneous measured value.

3.2 Final Yield (Y_F)

Final yield is defined as the total AC energy generated by the PV system for a defined period (day, month or year) divided by the rated output power of the installed PV system and is given by:

$$Y_F = \frac{E_{AC}}{P_{PV\,rated}}$$

3.3 Reference Yield (Y_R)

Reference yield is defined as the ratio of total in plane solar insolation H_t (kWh/m^2) to the reference irradiance G(1 kW/m^2).

$$Y_R = \frac{H_t(kWh/m^2)}{G(1kW/m^2)}$$

3.4 Performance ratio (PR)

Performance ratio is defined as the ratio of the final yield to the reference yield. It represents the fraction of energy actually available after deducting energy losses (Okello et al., 2015).

$$PR = \frac{Y_F}{Y_R}$$

3.5 Capacity Factor (CF)

The annual capacity factor (CF) is defined as the ratio of the actual annual energy output of the PV system to the amount of energy the PV system would generate if it operates at full rated power ($P_{PV\,rated}$) for 24 h per day for year and is given as:

$$CF = \frac{E_{AC,annual}}{(P_{PV\,rated} * 8760)}$$

3.6 Overall System Efficiency

The monthly overall system efficiency, $\eta_{sys,m}$ is defined as the ratio of the monthly energy output of the system to the total energy collected from the PV field during a month.

$$\eta_{sys,m} = \frac{E_{AC,month}}{(H_t * A_{PVaraay})}$$

where, E $_{AC,month}$ = total monthly energy output to the grid by the system (kWhr), H_t = total in plane solar insolation (kWh/m^2), $A_{PVarray}$ = total area of the PV modules.

Sharma and Goel (2017) define the overall PV system efficiency as the product of inverter efficiency and PV array efficiency.

3.7 Total Energy Losses

The total energy losses (L_T) of the PV system represent numerically the difference between the reference yield (Y_R) and the final yield (Y_F) (Okello et al., 2015) as:

$$L_T = Y_R - Y_F$$

4. Results and Discussion

The results of performance analysis of the 100 kW grid connected solar PV power plant located at Kharipati, Bhaktapur, Nepal for the year 2016 A.D is presented in this section.

The measured monthly average solar irradiance or insolation was minimum during January (3.05 kWh/m^2/day) and maximum in June (5.53 kWh/m^2/day). The mean monthly ambient temperature during the day hours varied from 14.80 ^oC (January) to 27.61 ^oC (June) as shown in Table 2. The average solar insolation at the location in the year 2016 was found 4.14 kWh/m^2/day, which is less than 4.573 kWh/m^2/day of Bhaktapur (SWERA, 2008). The annual average ambient temperature was 22.99 ^{o}C.

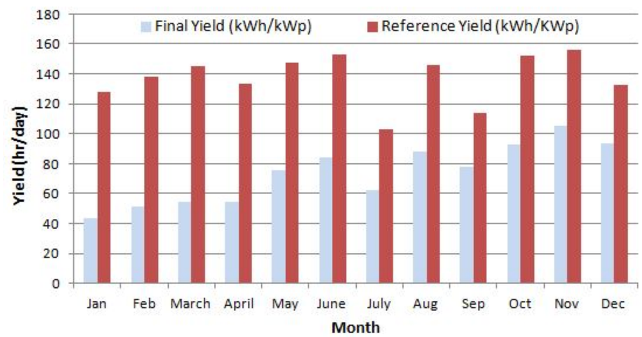

Figure 7: Measured monthly reference and final yield for the year 2016

The monthly reference yield varied from 103.3 kWh/kWp (July) to 156.2 kWh/kWp (November) and the final yield varied from 43.85 kWh/kWp (January) to 105.27 kWh/kWp (November).

Table 2: Surface meteorology of Kharipati, NEA Training Center, Nepal

Month	Sunlight (W/m^2)	Daily Solar Radiation ($kWh/m^2/day$)	Ambient Temperature (^oC)
January	296.01	3.05	14.80
February	363.13	3.98	18.84
March	365.68	4.31	21.22
April	399.14	4.43	24.34
May	407.48	5.06	26.53
June	438.94	5.53	27.61
July	279.99	3.57	25.29
August	412.87	4.81	27.24
September	313.38	3.68	25.83
October	376.93	4.21	24.65
November	378.81	3.85	20.73
December	314.89	3.16	18.76
Average	363.17	4.14	22.99

Figure 7 shows the variation of the monthly reference and final yields. Average monthly reference yield was 137.56 kWhr/kWp and final yield was 73.67 kWhr/kWp. The lowest value of final yield was observed in January because of more load shedding hours (network unavailability or faults) and highest at November 2016 because of no load shedding and high reference yield. Comparing yield value of the present system with value of others study, the average final yield of the present study was 2.42 kWh/kWp/day being a value higher than the value 2.31 kWh/kWp at Center for Energy Studies (CES), Pulchowk Campus, Nepal, (Bhattarai, 2013).

The total yearly measured energy output of the system in 2016 was 88.41 MWh with maximum during November (10.53 MWh) and minimum in January (4.39 MWh). The generated energy was comparatively more during the month October, November and December. At this period the grid network availability was more comparatively.

During January to April the load shedding or grid unavailability at location was more about 12-16 hours per day which resulted in low injection of energy to the grid. Grid unavailability kept the PV array system standby without generation, even though the sun was shining with good solar irradiance. Figure 8 shows the monthly and yearly produced electrical energy by the system.

The final produced energy during the period divided by the rated power of the system is 884.09 kWh/kWp, which is higher than that (843.15 kWh/kWp) produced by one kilowatt grid connected solar PV system at CES, Pulchowk Campus (Bhattarai, 2013). In city such as Tiruchirappalli, India, the energy output is 1600 kWh/kWp, in Port Elizabeth, South Africa is 1799 kWh/kWp, in Malaga, Spain is 1,339 kWh/kWp, in Crete, Greece is 1336.4 kWh/kWp, 1230 kWh/kWp in Calabria, Italy, 700 kWh/kWp in Netherlands, 730 kWh/kWp in Germany, 790 kWh/kWp in Switzerland, up to 1840 kWh/kWp in Israel, in northeastern Brazil is 1685.5 kWh/kWp and 1372 kWh/kWp in India (Carmo de Lima et al., 2017).

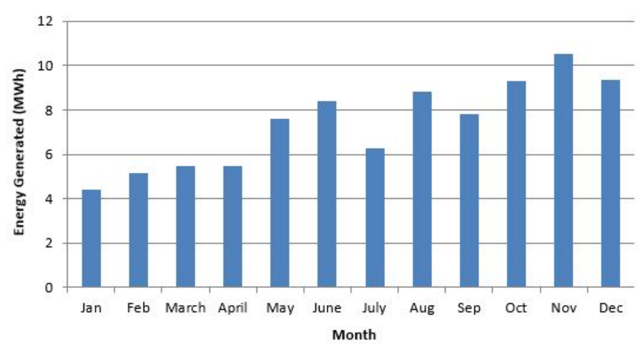

Figure 8: Measured monthly energy output for the year 2016

Figure 9 shows the performance ratio (PR) of the 100 kW grid connected PV system installed at NEA Training Center, Kharipati, Nepal varied from 34% to 70% with an annual average of 54%, being greater than that (48.8%) at CES, Nepal (Bhattarai, 2013). It was minimum 34% in January and maximum 70% in December. In India PR of different system varies from 55% to 94% (Kumar et al., 2014), from 55% to 83% (Sharma and Chandel, 2013) and from 71.3% to 82.1% (Kumar and Nagarajan, 2016). In Iceland it varies from 58% to 73% (Kymakis et al., 2009), in northeastern Brazil it varies from 72.9% to 91.9% (Carmo de Lima et al., 2017) and in New Zealand it varies from 76% to 79% (Emmanuel et al., 2016).

The solar irradiance in the collector plane was measured for whole day but the energy injection to the grid was not possible due to grid faults during load shedding periods. If the irradiance during grid unavailability period is excluded, the performance seems better.

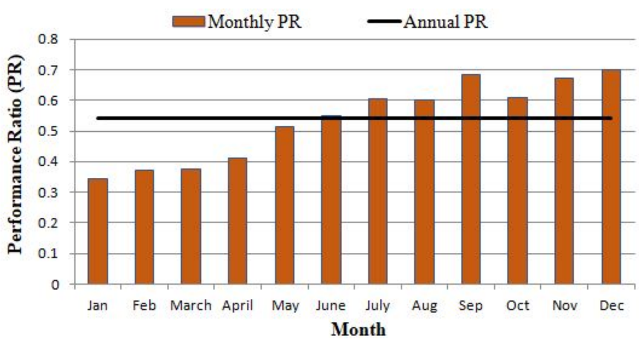

Figure 9: Monthly and Annual Performance Ratio

The Capacity Factor (CF) of the system varied from 5.89% (January) to 14.62% (November).The annual CF was found to be 10.09%.The energy generation in November was maximum so the CF was also maximum. Figure 10 shows the variation of capacity factor in the year 2016.

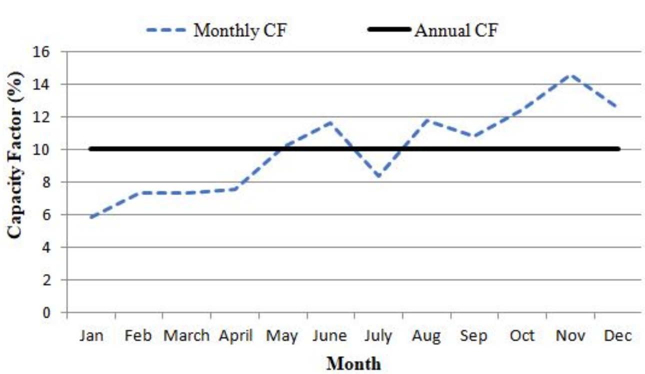

Figure 10: Variation of Capacity Factor

The overall system efficiency of the 100 kWp grid connected PV system varied from 5.02% (January) to 10.26% (December) with an annual average of 7.85%. The annual average PV array efficiency and Inverter (SG30KTL-M) efficiency of the system was found 8.09% and 97% respectively. Figure 11 shows monthly variation of overall efficiency.

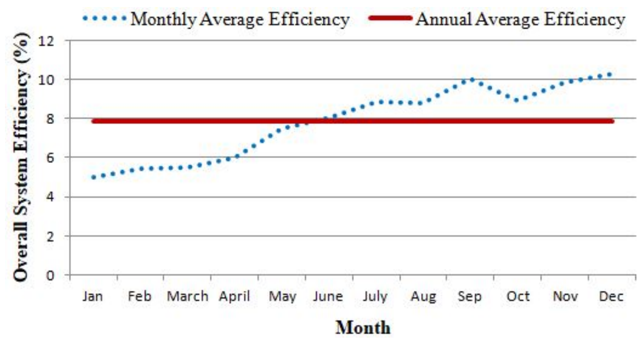

Figure 11: Variation of Overall System Efficiency

The total normalized energy loss was minimum 36.04 kWh/kWp in September and maximum 90.90 kWh/kWp in March whereas the loss percentage was minimum 29.88% in December and maximum 65.69% in January. In January the energy generated was very less compared with input solar irradiance on the plane. The total energy loss was 2.09 kWh/kWp/day.

5. Conclusions

- The average solar insolation of the location in the year was found 4.14 kWh/m2/day.
- The monthly reference yield varied from 103.3 kWh/kWp to 156.2 kWh/kWp and the final yield varied from 43.85 kWh/kWp to 105.27 kWh/kWp.
- The total yearly measured energy output of the system was 88.41 MWh with maximum during November (10.53 MWh) and minimum in January (4.39 MWh).
- The performance ratio (PR) varied from 34% to 70% with an annual average of 54%. The annual capacity factor was found to be 10.09%. The array, inverter and system efficiency of the plant were 8.09%, 97% and 7.85% respectively.

- Performance results show the good potential of producing electricity through photovoltaic solar energy in Nepal and helps policy makers and interested individual and organization by providing useful information on grid connected Photovoltaic System.

6. Acknowledgment

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