A Techno-Economic Analysis of Utility Scale Photovoltaic Plant (A Case Study of 1 MWp Plant at Trishuli)

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Abstract: This paper analyses one Megawatt peak utility scale photovoltaic based power plant with the aim to address the burning issues related to energy crisis in Nepal. Load shedding has created disastrous impacts in industrial, commercial and domestic sectors hindering economic growth and much needed improved quality of life. Grid tied photovoltaic can be a boon to decrease load shedding hours to some extent although it's claimed to be relatively costlier than hydro based electricity. But in comparison to thermal powered plant it is cheaper and environmentally friendly. The solar radiation condition of Nepal is very much favorable for solar technology application. About 58 Megawatt peak of utility scale photovoltaic potential is indicated in the tentative study at Nepal Electricity Authority owned areas at central region. This paper also highlights the techno-economic analysis of a one Megawatt peak utility scale solar photovoltaic plant. Site has been selected at Trishuli hydropower plant at latitude 27°55'27.9" and longitude 85°8'27.6" with total area of 10897 square meters. Designed utility scale plant consists of 280 Watt peak panel inclined at 30 degree facing south with total of 180 strings, 20 modules per string, two 500 kW central inverter, one 1250 kVA three phase three winding transformer,12 smart combiner box with string monitoring unit and appropriate cables, protection devices and controlling systems. Simulation of such utility scale plant is done using PVSYST with metrological data from Meteonorm. The result shows the plants energy output is 1768 MWh/year with 77.3% performance ratio, system yield of 4.81 kWh/kWp/day and capacity factor of 20.1819%. The plant is supposed to inject 0.1439% of the total deficit of 2013. If the same energy is fulfilled by diesel plant, it would have emitted 1414 ton of CO_2 emission. Economical analysis with PVSYST, with investment of NRs 109/Wp through a loan at 10.5% discount rate with duration of 12 years excluding taxes considering plant life as 25 years, indicates the cost of generated energy is about NRs 10.5 per kWh. Similarly, the project at discount rate of 9% with power purchase rate of NRs 10 per kWh considering plant life of 25 years, 5% escalation in operation and maintenance cost has positive net present value worth NRs 23,277,818 and IRR of 12%. Thus, utility scale PV grid tied plant in Nepal is technically and economically viable for meeting the energy deficit.

Keywords: PV, Photovoltaic, Grid Tied System, Design, Techno-economical analysis

1. Introduction

Nepal with surplus in hydro energy resources is ironically facing severe electrical energy crisis. The suppressed electricity energy demand deficit forecasted as greater than 100 MW/year is merely an indicator of how deep into trouble we are. Most of diesel generator run even at day polluting air, causing noise when we have plenty of solar energy striking on nation.

Historically, Nepal's power sector has been dominated by NEA, a 100% Government owned utility. NEA has shown recently interest in PV grid tied system. However in past it had successfully installed only standalone solar system 50 kW at Gamghadi and another 50 kW at Simikot [2]. JICA has installed recently 680.4 kWp Grid tied solar system in Sundarighat which is operating successfully.

The story of power position in Nepal is that of highest potential and lowest consumption. Environmental issues are mis-represented and this delays, or in some cases stops the development of hydropower project. Together with environmental and social impacts of this project and the government instability is the reason behind it. However, GoN lacks proper vision, planning and target. NEA has been unable to complete the projects within the allocated time frame which has caused time overrun as well as cost overrun.

Government of Nepal (GoN), through its policy and program has aimed to minimize the load shedding in Nepal which has led to search for quick options for production of electricity. It has prioritized hydro power development and development of associated transmission lines and substations. It has even shown interest on utility scale grid tied PV and rooftop PV installation.

There are many solutions to increase energy availability in a quick manner without polluting the environment .Using green solar energy; nonetheless one is utility scale PV grid tied system and other is grid tied rooftop PV system. The system consists of solar panels and an inverter, so smart that it autonomously regulates itself to synchronize with the grid, similar to a power plant. Nepal is blessed with solar resource and has huge potential to harness the energy. It has on average more than double the solar isolation (kWh/m^2/day) than Germany -the world leader in PV installations. In the last five years, the total PV installed in Germany has soared from 6 GWp to 36 GWp.

2. Need of utility scale PV

Nepal is suffering from the lagging energy supply and the demand is increasing rapidly from year to year. It is difficult to meet this current and future demand without stimulating the energy vision. Energy demand is increasing at faster pace than energy supply rate. Load shedding hours of previous year was 18 hrs which decrease to 13 hrs this year and expected to increase in forthcoming years. We are bearing load shedding even at day when we have plenty of solar energy potential. Proper energy mix and use of renewable energy is must to solve the problem in a quick manner although average cost of electricity per unit may rise. Such rise in cost should be minimized by proper incentive by GoN with minimum loan rate facility and FIT (feed in tariff) facilities. Proper concept must be developed for quick load shedding minimization. To increase energy availability at a quicker rate, grid tied PV plant can be fruitful to decrease load shedding hours to some extent. PV power plant can be utilized to fulfill energy demand and decrease use of diesel generators. Major significant cost in erection of such plant are panel cost, high cost of land(near load centers). Land acquisition near urban load center for placement of utility scale is problematic, risky and time consuming and may have future shading problems as well. Load shedding seems to continue for decade as growth is likely to increase hugely as Nepal enters into phase of economic revolution through more industrialization. In such cases too, peak demand would shift to day and thus grid tied PV would be more beneficial than today. NEA owned plant areas may be suitable for optimizing and utilizing resources properly.

3. Literature Review

3.1 *Supply and demand scenario*

Out of the theoretical potentiality of 83000 MW of hydropower in Nepal, only 704 MW has so far been connected to grid whereas peak demand is 1207 MW[2].

Table 3.1:Demand scenario at peak day of 2013 (NEA 2012/2013)[2]

Morning	Day	Evening	Night	MWh/day
965 MW	660	1207	540	16300
Capacity				
Wet Season = 912 MW(including 190 MW import) Dry Season = 520 MW				

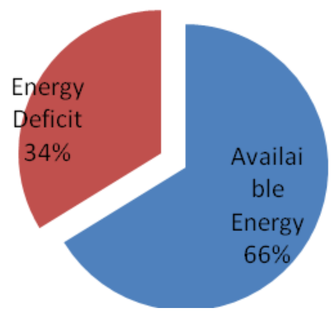

Figure 3.1 : Energy supply and deficit [2]

3.2 *Load shedding history*

From the report of annual journal published by NEA, maximum hours of load shedding was greater than 16 hours.This shows where we have missed and lost our track.

Table 3.2: History of load shedding [2]

Fiscal Year	Maximum hours of load shedding
2008-2009	16
2009-2010	12
2010-2011	14
2011-2012	12
2012-2013	14

3.3 *Cost of alternative used during load shedding*

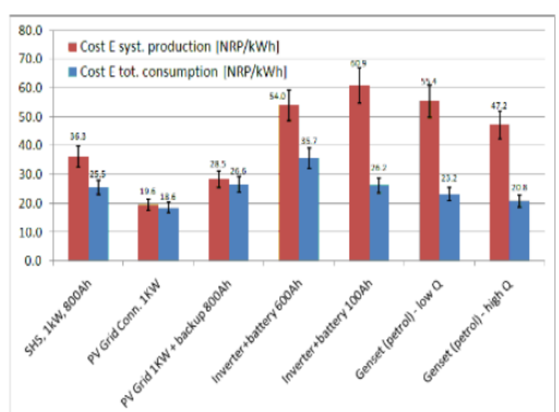

Figure 3.2 : Cost per kWh with 100% cash investment[1]

The research on “Feasibility study on Grid connected PV system in Nepal” shows that the cost of energy from inverter-battery system is highest. Similarly, cost of energy from diesel genset is the next highest. Cost from grid tied PV system without battery is seen minimum.

3.4 Power exchange status

In average Nepal is importing nearly 190 MW power from different connection points. Nepal is also entitled to receive 70 GWh of energy annually from Tanakpur in the far west under the Mahakali Treaty and 10 MW power according to the Koshi contract. Nepal is planning to import further energy to mitigate load shedding. This has increased significant trade deficit with India too. Many Indian states are currently bearing load shedding too. So, Nepal cannot rely fully on them. Nepal is paying higher rate of tariff with Indian utility companies during purchase. The highest rate of purchase is 10.73 NRs/kWh during purchase of extra power on free market trading basis.

3.5 PV system in Nepal

Mainly PV systems have been popular in standalone system at rural places without grid infrastructure. Solar home systems are popular in urban areas too as an alternative to load shedding. Due to high initial investment, its use has been limited and replaced by inverter-battery system. High cost of batteries and low life of batteries have been major problem of standalone systems.

Figure 3.3 : Grid tied PV at Sundarighat

In context of Nepal, the grid connection of PV power just began in 2012 with 680.4 kW grid tied plant in Sundarighat funded by JICA operating successfully. It supplies power to the load of Kathmandu through 11 kV feeder.

3.6 Grid tied system in world

The grid tied PV system installation is increasing day by day. This shows the focus of nations on clean and renewable energy. In many developed countries, PV utility scale has reached grid parity. Germany is the leading nation with highest installation. Largest photovoltaic power plants in the world is “Topaz Solar Farm” in USA — 550 MW (300 MW completed up through January 2014)[10].Among Asian countries ; China, Japan and India has highest installations of PV.

3.7 Grid tied system components

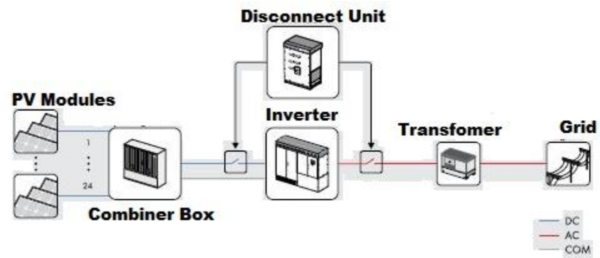

Figure 3.4: Block diagram of grid tied PV system[3]

The main components include [4]:

• **Solar PV modules –** These convert solar radiation directly into electricity through the photovoltaic effect in a silent and clean process that requires no moving parts. The photovoltaic effect is a semiconductor effect whereby solar radiation falling onto the semiconductor PV cells generates electron movement.

• **Module mounting (or tracking) systems –** These allow PV modules to be securely attached to the ground at a fixed tilt angle, or on sun-tracking frames.

• **Inverters –** These are required to convert the DC electricity to alternating current (AC) for connection to the utility grid. Many modules in series strings and parallel strings are connected to the inverters.

• **Step-up transformers –** The output from the inverters generally requires a further step-up in voltage to reach the AC grid voltage level. The step up transformer takes the output from the inverters to the required grid voltage (for example 11 kV, 33 kV, 66 kV, 132 kV depending on the grid connection point and requirements).

• **The grid connection interface –** This is where the electricity is exported into the grid network. The substation will also have the required grid interface switchgear such as circuit breakers and disconnects for protection and isolation of the PV power plant as well as generation and supply metering equipment.

3.8 Performance coefficients

• Performance Ratio

The quality of a PV power plant may be described by its Performance Ratio (PR). The PR, usually expressed as a percentage, can be used to compare PV systems independent of size and solar resource. The PR may be expressed as:

$$PR=\frac{\text{AC Yield(kwhr)}}{\text{(Total installed capacity*irradiation at array kwhr/m2)}}$$

• Capacity Factor

The capacity factor of a PV power plant (usually expressed as a percentage) is the ratio of the actual output over a period of one year and it’s output if it had operated at nominal power the entire year, as described by the formula:

$$CF=\frac{\text{(Energy generated per annum (kWh))}}{\text{(8760(hours / annum)}\times\text{Installed Capacity (kWp))}}$$

• Specific Yield

The “specific yield” (kWh/kWp) is the total annual energy generated per kWp installed. It is often used to determine the financial value of plant and compare operating results from different technologies and systems.

3.7.3 Quantifying the Solar Resource

Site selection and planning of PV power plants requires reliable solar resource data. Power production depends linearly on the plane of array irradiance, at least to a first approximation. The solar resource of a location is usually defined by the values of the global horizontal irradiation, direct normal irradiation and diffuse horizontal irradiation. Two type of solar resource may be available at a location; Satellite derived data (e.g., NASA) and land based measurement data(measured by sensors like Pyranometers).

3.8 Economical Analysis

Following terms are considered for the project[5]:

IRR represents the true interest yield provided by the project equity over its life. It is also referred to as the return on investment or the time-adjusted rate of return and calculated by finding the discount rate that causes the net present value of the project to be equal to zero. If IRR is equal to or greater than the required rate of return then the development of the solar PV power plant will likely be considered financially acceptable.

SPP – which represents the length of time that it takes the project to recoup its own initial cost, out of the cash receipts it generates – is calculated using the total initial costs, the total annual costs and the total annual savings. The basic premise of the payback method is that the more quickly the cost of an investment can be recovered, the more desirable is the investment.

NPV of the project, which is the value of all future cash flows, discounted at the discount rate is calculated. Under the NPV method, the present value of all cash inflows is compared against the present value of all cash outflows associated with an investment project. NPV – which is the difference between the present value of these cash flows – determines whether or not the project is generally a financially acceptable investment. Positive NPV values are an indicator of a potentially feasible project.

4. Methodology

Only central region hydropower plant area are considered in view of minimization of cost as well as it is assumed that load center is Kathmandu. The possible land/area of hydropower plant are selected for installation of solar PV system. The effective area is calculated by measuring areas by Google Earth. Assuming 1 MWp per 10000 sq meter for mono-crystalline panel, potential of areas are developed. Major data about electrical components (generator, transformer) of hydropower plant are obtained. Transmission line capacity, length, conductor type, voltage are obtained. Switchyard capacity is obtained. Monthly solar insolation values are obtained from NASA, METEONORM and SWERA report. Proper flat surface area is selected near the switchyard that can accommodate in same switchyard. Simulation of designed PV system is made using PVSYST software. 1 MWp PV system is designed and available energy from the plant is calculated. Economical analysis of complete PV system is done using same PVSYST software as well as separately.

5. Data Analysis and Result

5.1 Site Selection

The site selected is near Trishuli Hydropower plant approximately 800 meter far from the switchyard. Site consists of different kinds of plants and some old buildings. Site must be prepared and undergo Initial Environmental Examination. In this paper, it has not been considered during the site selection.

Figure 5.1 : Site selected nearby Trishuli plant

Table 5.1: Details about Area

Area (Sq Meters)	Bounding Box Maximum(Degrees Minutes Seconds)	Bounding Box Minimum(Degrees Minutes Seconds)
10,897	27°55'27.9", 085°08'27.6"	27°55'23.2", 085°08'22.6"

Table 5.2: Proposed Evacuation Scheme

Transformer Rating Available near site	Transmission Line
6 x 5 MVA; 6.6/66 kV + 1 x 10 MVA; 33/11 kV	6.6 kV Weasel Conductor to 0.9 km far switchyard or 11 kV Dog 2-3 km conductor

5.2 *Metrology and Geographical Data:*

Table 5.3: Metrological data [7]

Time Zone	5:45		GMT	
Albedo	0.2			
Values	GlobH	DiffH	Temp	Wind
Month	kWh/m²	kWh/m²	°C	m/s
January	145.7	27.6	12.2	1.02
February	149.8	33.9	16.8	1.46
March	191.9	52.1	22.5	1.76
April	210.3	66.3	28	2.21
May	223.8	85.6	30	2.59
June	187.2	96	29.6	2.49
July	156.2	88	27.5	2.04
August	151.9	82.8	27.2	1.97
September	154.8	72.6	26.4	1.79
October	169.6	38.1	24.1	0.93
November	149.1	27.6	19.4	0.57
December	116.6	31.9	14.2	0.69
Year	2006.9	702.5	23.2	1.63

The Data is derived from NASA as well as Meteonorm. Average yearly horizontal radiation of NASA is 5.23 kWh/m^2/day [6] and that of Meteonorm is 5.48 kWh/m^2/day [7]. Annual global solar radiation at Trishuli hydropower plant located district Nuwakot according to SWERA is 4.191 kWh/m^2/day and on tilted plane is 5.722 kWh/m^2/day with wind power density of 5 W/m^2 [8].Thus data from different sources have minimum certain deviation. In this study, Meteonorm data is used.

5.2.1 *Climate and Nature Condition*

Maximum ambient temperature: 40 °C

Minimum ambient temperature: 0 °C

Annual average ambient temperature: 35 °C

Worst Maximum Cell temperature: 70 °C at noon(taking 30 °C rise)

Worst Minimum Cell temperature: 0 °C

Maximum Wind Speed: 34.4 m/s or 124 km/hr

Rainfall: 1500 mm/annum

Relative humidity maximum = 100%

Relative humidity minimum = 20%

Altitude = 500 m (MASL)

Atmospheric pollution = light

Regional Factor for Seismic Coefficient: Z=1.0

Soil Type : Wet Clay

5.2.2 *Solar path diagram*

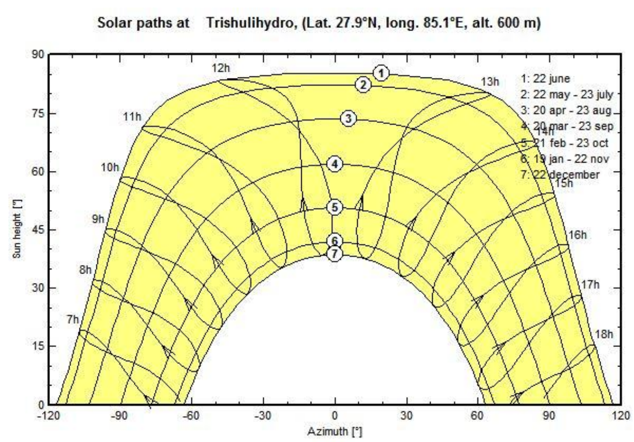

Figure 5.2: Solar path diagram

5.3 *Design*

From preliminary assessment using PVSYST, we can install DC Power of 1696 kWp without any inter row spacing. From detail assessment considering row spacing 1 MWp system can be installed.

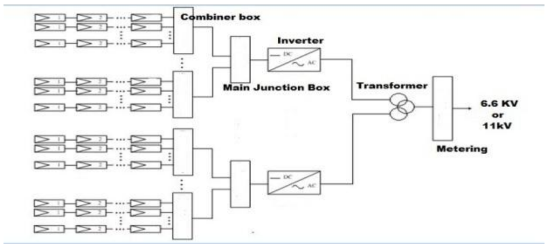

Figure 5.3 : Proposed configuration of plant

5.3.1 Selection of Module

Yingli Modules YL280C-30b (Panda) is selected for the design with module efficiency of 17.2%.

Table 5.4: Module data

Module data	At STC,AM 1.5,25 °C
Power	280 W
Module eff	17.20%
V at Pmax	31.3 V
I at Pmax	8.96 A
Voc	39.1 V
Isc	9.5 A
Temp coff Pmax	-0.41%
Temp coff Voc	-0.31%
Max. system voltage	1000 V

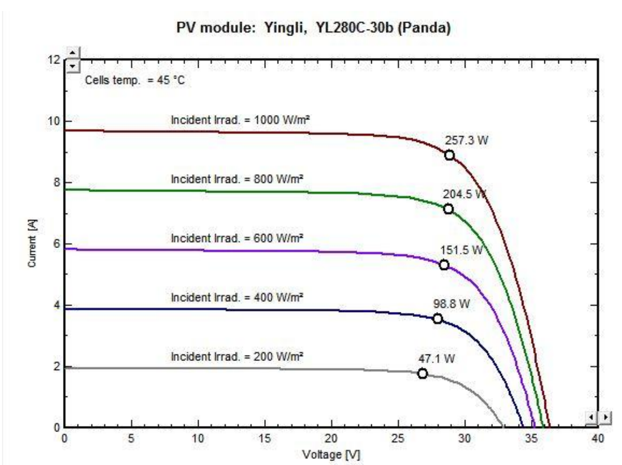

Figure 5.4: Module characterstic curve

5.3.2 Selection of Mounting Structure

Since tracking technology is expensive as well as increases operation and maintenance cost, fixed axis mounting for simplified structure would be better decreasing overall capital investment. Fixed array will require less land per MW than single axis and Dual axis. Fixed galvanized steel structure with concrete footings 1 foot above the ground and oriented towards south at 30 degree is proposed. The structure is mounted on steel pillars on concrete piers. Mounting structure layout will be as shown in figure 5.5 obtained after shadow analysis. The mounting structure has wind bearing capacity above 124 km/hr.

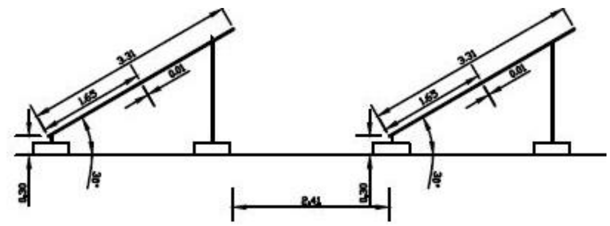

Figure 5.5 : Side view of proposed mounting structure

5.3.3 Selection of Inverter

Two 500 kW SMA Central CP 500 model is proposed with possibility of operation in outdoor as well.

- The MPPT voltage range (V_{MPPT})= 430 - 820V
- Maximum input Voltage (V_{max})= 1000 V DC
- Maximum input Power (P_{max}) = 560 kW DC
- Nominal AC Output power(P_{AC}) = 500 kW at unity pf & 50 °C 550 at 25 °C
- Nominal AC Voltage (V_{AC}) = 270 V
- AC output Maximum Current (I_{max})= 1176 A
- Connection: 50Hz grid frequency and 3 phase 4 wire connection
- The efficiency of inverter = 98.6 %(Max)

5.3.4 Summary of proposed design

Table 5.5: Summary

System Overview	
SPV array peak power	1008 kWp
No of strings	180
Tilt Angle	30
Inverter	Central inverter MPPT TL /3 phase
Total no of inverter	2
Strings per inverter	90
No of modules per string	20

Components	Specification	Remarks
Solar PV modules	Power=280Wp Voc =39.1 V Vmp = 31.3 V Isc = 9.5 A Imp=8.96 A	YL-280C-3b(Panda)
Inverters	2x500 kW, 3 phase MPPT range = 430-820 V, Efficiency=98.6%	SMA Central
Transformer	1250 kVA,Three winding three phase,ONAN,50 Hz,6.6/0.27 kV	
Switchgear HV	7.2 kV ; 630 A,250 MVA ,25 kA	VCB
Isolator	7.2 kV;630 A	
Main Box,DC/AC Disconnect	1000 V, 1600 A, 6 inputs,6 DC switches , AC circuit breaker ,1600A 3P,42kA	SC-Disconnect US(SMA)
Smart Combiner Box	16 input,8 measuring channels, 25A_{DC}, disconnect switch 200A	SSM-8-21(SMA)
Fuse	15 A, 1000 V	SMA
Cable	4 mm^2 DC solar cable 1000 V DC UV protected ,240 mm^2 DC XLPE 1000 V,1500 mm2 AC XLPE 600 V, 240 mm^2AC XLPE 6.6 kV	
Surge Arrester	SPD Combination(1/2);Maximum current flow capacity= 40 kA ;Voltage protection level= 3.8 kV	OVR PV 40 1000 P TS
Lightning Arrester	Early Streamer Emission (ESE),5 kV	
Earthing kit and Mat	Grounding resistance of < 10 ohm	

5.3.5 Simulation results using PVSYST

From simulation, total energy injected to the grid is 1768 MWh per year. If same energy is produced from a diesel plant, 1414 ton of $C0_2$ GHG yearly (taking 0.8 ton for 1 MWh) would be emitted. If plant life is taken as 25 years then 35,350 ton of CO_2 GHG emission is saved from the plant.

Its contribution towards fulfilling deficit is as shown in below.
Deficit in fiscal year 2012/2013=1228 GWh

$$\% \text{ of deficit it will meet} = \frac{\mathbf{1768}}{\mathbf{1228000}}\,\boldsymbol{x}\ \mathbf{100}\ \%$$

$$= \mathbf{0.1439}\ \%$$

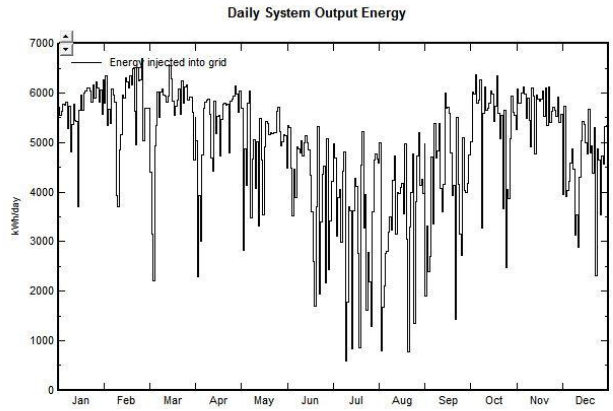

Fig 5.6: Energy injected to grid

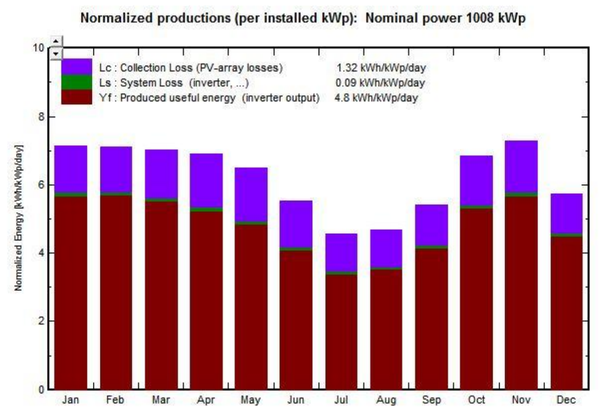

Fig 5.7 : Normalized productions per kWp

Normalized Performance Coefficients

	Yr	Lc	Ya	Ls	Yf	Lcr	Lsr	PR
	kWh/m².day		kWh/kWp/d		kWh/kWp/d			
January	7.14	1.356	5.78	0.107	5.68	0.190	0.015	0.795
February	7.10	1.305	5.80	0.104	5.69	0.184	0.015	0.802
March	7.02	1.392	5.62	0.099	5.53	0.198	0.014	0.787
April	6.90	1.552	5.35	0.101	5.24	0.225	0.015	0.760
May	6.50	1.550	4.95	0.093	4.85	0.239	0.014	0.747
June	5.52	1.332	4.18	0.078	4.11	0.242	0.014	0.744
July	4.55	1.078	3.47	0.069	3.40	0.237	0.015	0.748
August	4.68	1.085	3.60	0.072	3.53	0.232	0.015	0.753
September	5.42	1.193	4.23	0.079	4.15	0.220	0.015	0.765
October	6.84	1.421	5.42	0.101	5.32	0.208	0.015	0.778
November	7.29	1.497	5.79	0.103	5.69	0.205	0.014	0.780
December	5.73	1.139	4.59	0.080	4.51	0.199	0.014	0.787
Year	6.22	1.324	4.89	0.090	4.80	0.213	0.015	0.772

Fig 5.8 : Normalized performance coefficients

Summary of Performance Coefficients are:

Capacity Factor = 20.165 %

Relative Yield = 6.22 $kWh/m^2/day$

System Yield = 4.80 kWh/kWp/day

Specific Yield =1754 kWh/kWp

Performance Ratio =77.3 %

5.4 Economical Analysis Result

From the economic analysis using PVSYST software with gross investment without taxes 109 NRs/Wp with loan duration of 12 years at a bank loan rate of 10.5% shows energy cost of 10.5 NRs/kWh .Assumption for cost breakdown is taken as CERC renewable tariff commission draft report 2014 [11]. Degradation , land cost are not included. Deration factor of 0.75% for each year is considered rather than degradation cost.

Table 5.6: Cost Breakdown

PV modules	Rs 58996224
Supports/Integration	Rs 8064000
Inverter	Rs 8064000
Settings wiring	Rs 9676800
Power evacuation	Rs 2419200
Civil, general works	Rs 9676800
Preliminary expenses	Rs 11128320
Contingency	Rs 1612800
Total	Rs 109638144

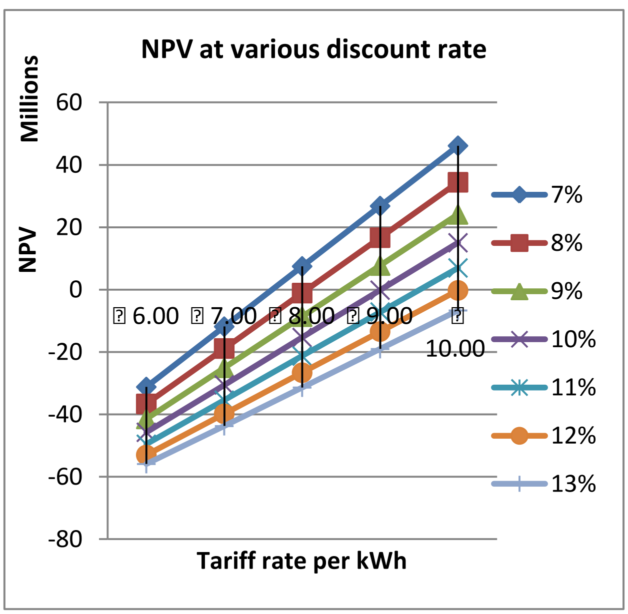

Fig 5.9 : NPV at various tariff and discount rate

From separate economical analysis with discount rate 9%, operation and maintenance cost of 20 lakhs/year with escalation of 5% and PPA tariff 10 NRs/kWh ,net present value is positive making project feasible.NPV of NRs 23,277,818 and IRR of 12% is obtained from the economical analysis.

6. Conclusion

The utility scale PV grid tied system with example of 1 MWp system in NEA owned area of central region shows that the PV plant is technically and economically feasible which can significantly contribute to minimization of energy deficit some to extent.

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