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Techno-Economic Analysis of Solar PV System: A Case Study of 1MWp Plant at Sikta Irrigation Canal

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Abstract **Original Research Article**

This paper simulates the feasibility of installing a grid-connected photovoltaic (PV) system above the Sikta Irrigation Canal, Kohalpur, Province No. 5, Nepal. The study was conducted to evaluate the technical and financial aspects of PV for grid connected system. 1 MWp grid-connected PV system simulation is carried out with PVsyst, its impact on grid before and after synchronization is also performed using ETAP software and finally the financial analysis is performed. The simulation is expected to help in exhibiting the advantages and challenges of installing grid-connected PV system above canal. This paper gives more insight about the technical and financial viability of canal top solar PV system in context of Nepal.
Keywords: Canal top, Grid-connected, photovoltaic, PVsyst, Solar PV, Technical Analysis, Financial Analysis, ETAP, Simulation.

Introduction

The importance of renewable energy resources which are environmentally friendly and reliable energy technology has been increased for a substitute to replace fossil fuels, related to the current energy shortage, global economic growth and environmental pollution [1]. Nepal is blessed with solar resource as it lays at 30◦ Northern latitude which is ideal and there are over 300 days of sunshine annually. Further the annual average solar insolation is 5kWh/m^2 per day [2]. These conditions are perfect for harnessing solar energy for various conversion technologies.

Grid connected PV power generation system has the advantage of more effective utilization of generated power [3]. Canal top solar PV technology has been already implemented in India, but this paper is intended to see its technical and financial feasibility in context of Nepal.

Recently in Nepal due to political stability and stable government the development the demand of land is expected to go high resulting increase in the price of land. Land acquisition has been very difficult in Nepal for development of infrastructure as the cost of land has gone very high. Apart from land acquisition, issues like demand for high compensation amounts by locals, lengthy bureaucratic process, lack of coordination between ministries and issues related to forest clearance had made the project cost and time high. The large scale solar PV system requires large area of land. Due to high land price and requirement of large area of land the PV project may not be financially suitable.

To mitigate this problem, the canal top solar PV will be more suitable. The space above the irrigation canal can be utilized to install the solar PV system. In Nepal the space above such canal can be utilized for the installation of solar PV. Installing the solar PV above the canal has following advantages:

- No acquisition of Land required results less overall cost of project
- Acquisition of land takes more time. As acquisition of land is not required low gestation period.
- Social issue is minimized
- Utilization of space above the irrigation canal
- Water is readily available for the cleaning of large number of PV panels increasing efficiency
- Increasing in efficiency of solar PV due to cooling effect [4]
- Saving of water due to evaporation [5]

Research Methodology

The research began from the literature review, study of INPS system, study of international standards, data collection and then modeling of utility scale photovoltaic plant using PVSYST. Further, economic analysis is done. After thorough review of literature, sikta irrigation canal was considered in view of minimization of cost as it is near the assumed load center i.e. Kohalpur. The area above the sikta irrigation canal was selected for installation of utility scale grid tied PV system. The effective area was calculated from available Auto-CAD drawing of canal from department of irrigation. Major data about nearest 132/33/11kv Kohalpur substaion was obtained. Transmission line capacity, length, conductor type, voltage data were obtained. Switchyard capacity of each nearby substation of study areas was obtained. Monthly solar insolation was obtained from METEONORM report. The components for grid tied 1 MWp utility scale PV System was selected. Simulation of designed PV system was made using PVsyst [6] software and calculation of energy to be injected from the selected plant was done. The simulation results are validated by analytical calculation. The synchronization of designed solar PV plant was modeled in ETAP [7] software and its impact on national grid before and after synchronization were done. Financial analysis of complete PV system is done in EXCEL and LCOE was calculated.

RESULTS AND DISCUSSION

The canal length of south facing stretch of 550 meter and width of 20.5 meter is considered for the installation of solar PV above it. The technical simulation result for 1MWp grid-connected system work consists of meteorological data, incident energy, system losses, energy output, performance ratio and the impact on the grid before and after synchronization. The table 1 shows the data input to the PVsyst software. The parameters considered for PVsyst simulation software are mentioned in table 2.

Table-1: Meteorological data input for the PVsyst simulation

Parameter	Values
Location of site	28.17º Latitude, 81.68º Longitude
Global Irradiance	5.41 kWh/m^2.day
Diffuse Irradiance	2.04 kWh/m^2.day
Maximum Ambient Temperature	40 ℃
Wind Velocity	1.4 m/s
Azimuth Angle	0º
Tilt Angle	30º

Table-2: Parameters considered for PVsyst simulation

Parameters	**Values**
PV module selected	320 Wp
Total Number of modules	3264
Number of modules in series	17
Number of strings	192
Inverter selected	2 No. of 500kW
Combiner Box	12 Nos. of 16 String
Transformer	1250kVA, 0.3/11kV

PVsyst Simulation Output

From the simulation it is found that the yearly energy production from the PV plant shall be 1860 MWh/year with normalized production of 4.88 kWh/kWp/day and performance ratio of 0.799.

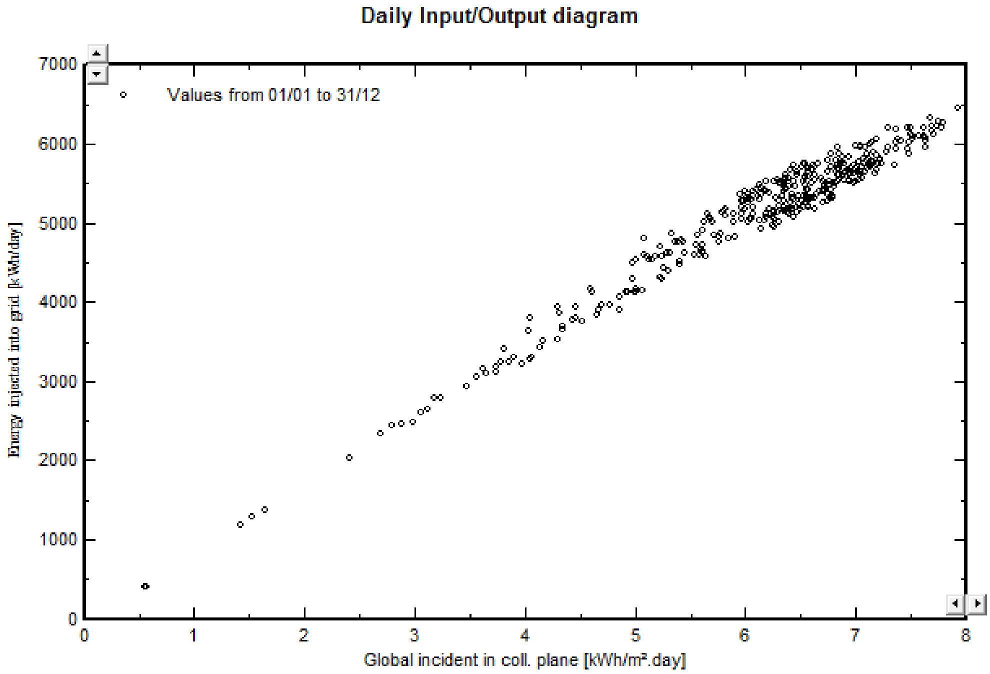

Fig-1: Daily energy injected from 1MWp PV into grid as function of global solar incident

The performance ratio, which indicates the ratio of actual yield and target yield, in the simulation was found to be 79.9%. Data showed that about 25% of solar energy in the analyzed period is not converted in to usable energy due to factors such as losses in conduction, thermal losses, contact losses, the module and inverter efficiency factor etc. Commonly the value of performance ratio ranges from 60% to 80% [8]. The percentage lost energy during energy generation process unitll finally injected into the grid is showed in figure… It is seen that the biggest lost occur on the array which is 16.8%.

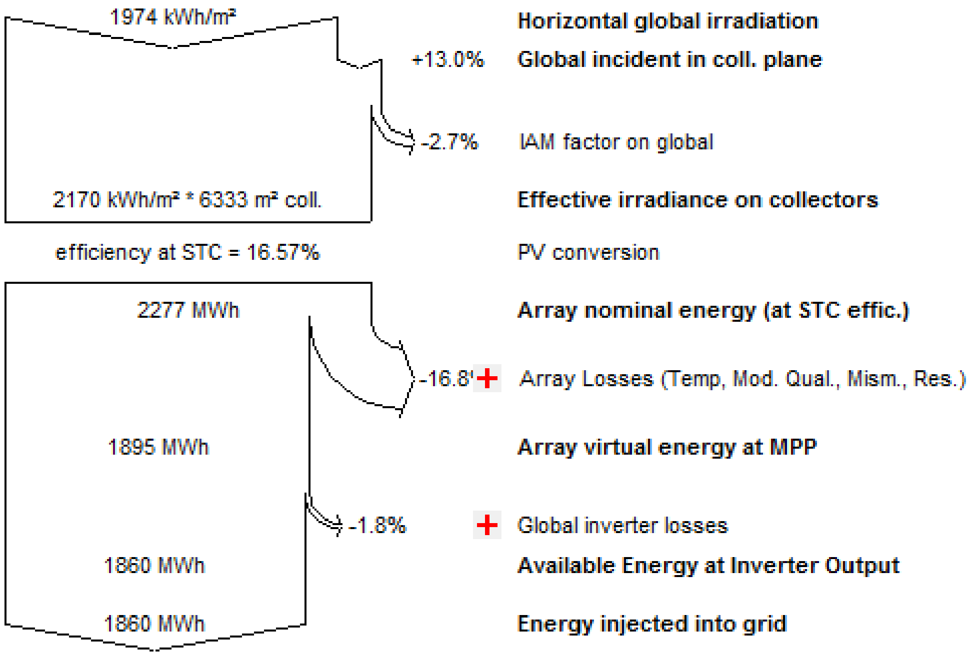

Fig-2: Grid connected PV system loses diagram

ETAP Simulation Output

The designed 1MW solar PV plant will be connected to 11kV busbar at 132/33/11kV Kohalpur substation. For that the model of the Integrated Nepal Power System (INPS) was prepared in ETAP software and the 1MW solar PV system was synchronized in 11kV voltage level. From the synchronization simulation on ETAP the voltage profile of the grid was found to be improved.

Voltage at the 11kV Bus 15 before synchronization: 91.66%
Voltage at the 11kv Bus 15 after synchronization: 92.07%
Voltage at the 33kV Bus 12 before synchronization: 93.87%
Voltage at the 33kV Bus 12 after synchronization: 93.99%
Voltage at the 132kV Bus before synchronization: 98.51%
Voltage at the 132kV Bus after synchronization: 98.59%

The simulation results of load flow analysis show that the synchronization of the designed solar PV is technical possible and after synchronization the voltage profile of the 11kV, 33kV and 132kV bus has been improved. The load flow analysis also shows that the generated energy from solar PV is consumed locally at Samshergunj.

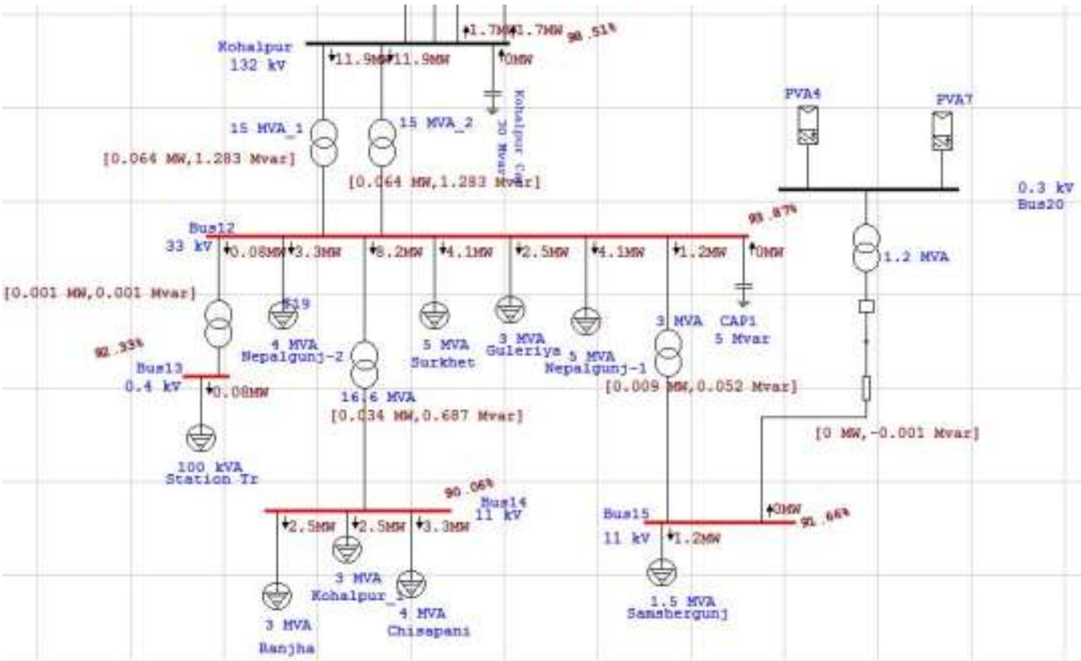

Fig-3: Load flow analysis of the gird before synchronization of solar PV

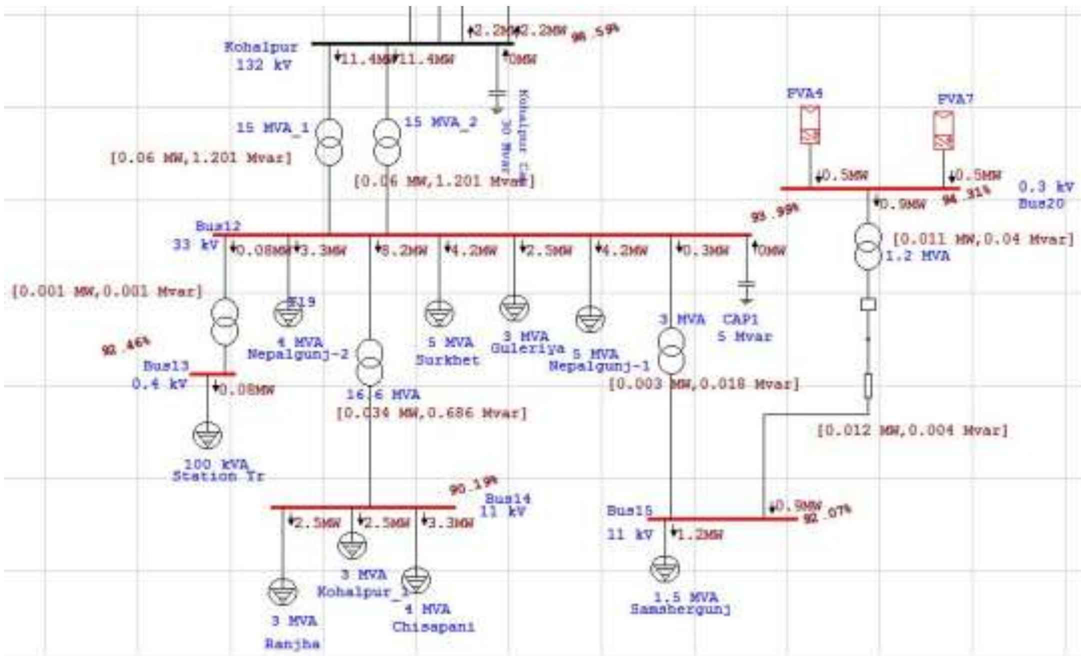

Fig-4: Load flow analysis of the gird after synchronization of solar PV

The features of Sikta Irrigation canal portion selected for installation of 1 MW canal top Solar PV is listed in table 3 and section drawing of canal is shown in figure

Table-3: Features of Sikta Irrigation canal

Length of canal occupied by solar structure	555 m
Bed width of canal	8.5 m
Side Slope	1.5:1
Top Width of canal	20.5 m

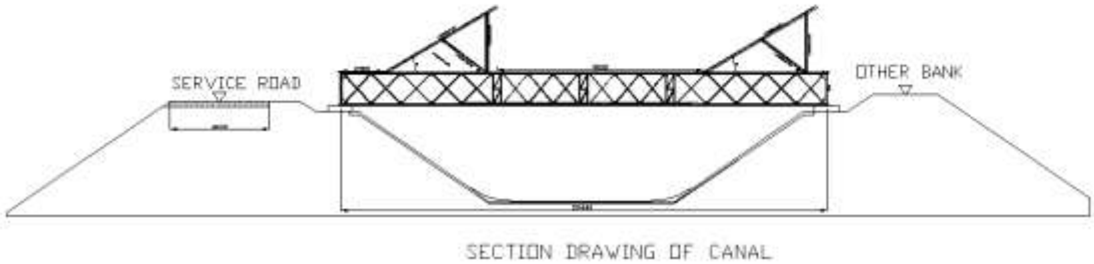

Fig-5: Sectional detail of Sikta irrigation canal

RESULTS AND DISCUSSION

Technical Analysis

The result of the PVsyst simulation indicated the highest level of solar radiation in sikta irrigation canal; Kohalpur occurred with an average insolation 5.41 kWh/m2/day. For the simulation the solar PV module selected is 320Wp, number of modules in series is 17 and number of string is 192 having total 3264 numbers of PV modules. Two number of 500kW central inverter is considered for the 1 MW solar PV system. From the simulation the yearly energy production is found to be 1860 MWh/year with an efficiency of 13.53%. Total 12 numbers of 16 string combiner box is selected for the plant. The output of the inverter is at 0.3kV voltage level hence for the connection of the plant with grid one 1250kVA; 0.3/11kV transformer is selected. Total 550 meter of south facing canal of width 20.5 meter stretch is found feasible as per site condition. The panels will be installed in two rows with inter-row spacing of 9.5 meter as shown in figure 6. The 550m stretch of canal is divided into 15 m span. Each span has the two rows having 90 numbers of modules and two numbers of beams as shown in figure 7.

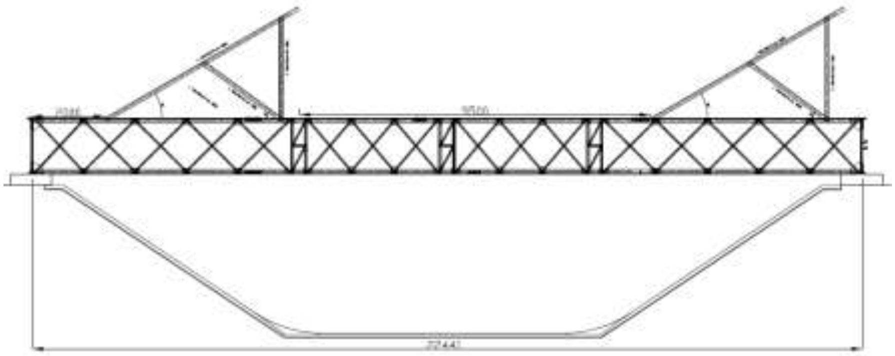
Fig-6: Sectional view of canal along with PV mounting structure

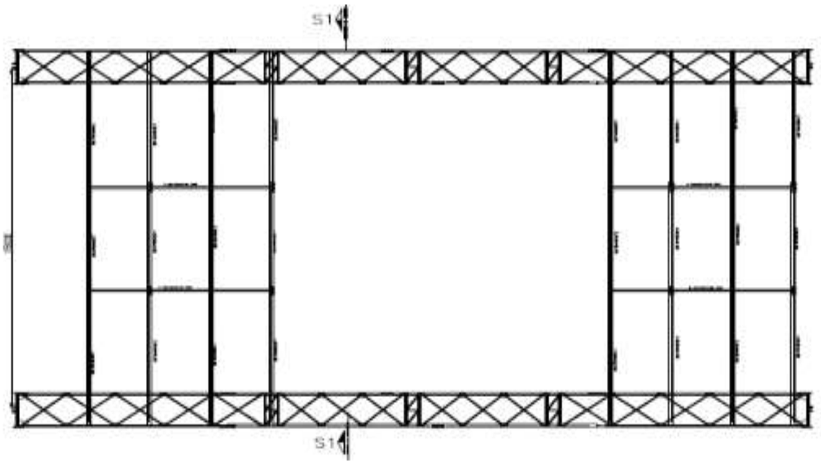

Fig-7: Plan of PV mounting structure for typical 15 m span

The designed canal top solar PV is connected to 132/33/11kV Kohalpur substation which is 1.5km from the plant. The PV plant is synchronized at 11kV voltage level. The simulation for the synchronization of the PV system is performed in ETAP software and the voltage profile of the grid is found improved before and after the synchronization of the plant.

Financial Analysis

The market survey on the price of solar PV system component was carried out through internet. The prices for the steel structure and other electrical equipment were taken from the latest tender unit rate of Nepal Electricity Authority as well as quotation from the vendors. The cost component price for installation of 1MW solar PV above the sikta irrigation canal is summarized in table 4. The cost for transportation of equipment and installation is considered 20% of supply price. For the energy calculation solar panel degradation rate is considered 0.5% per year. The lifetime for PV panel is considered about 25 years. As per Nepal Electricity Authority the purchasing energy rate from solar PV system is NRs. 7.3/kWh [9] with no any price increment in future. Hence, same energy price rate is considered for the financial analysis.

Table-4: Breakdown of the total project cost

S.N.	Description of Work	Total Amount (NRs.)	Percentage
1	Solar Panels	45,000,288	28%
2	Electrical Equipment	46,102,795	29%
3	Steel Structures	52,455,381	33%
4	Civil Works	13,132,558	8%
5	Working capital	4,700,731	3%
	Total Cost	161,391,753	100%

For the financial analysis is performed in two scenarios
Scenario 1

Table-5: Details of financial analysis scenario 1

Financial Mix	70:30 (70% Debt and 30% Equity)
NPV	NRs. 114,749,680
LCOE	3.97 Rs/kWh
IRR	5.32%
WACC	9.46%
Payback Period	12.83 years

In this scenario the IRR is less than WACC, hence the project does not seem to be feasible financially. Further, the sensitivity analysis is performed and it is found that in this scenario in the energy sales rate is greater than 10.3 Rs/kWh than the IRR will be greater than WACC and the project will be financially feasible.

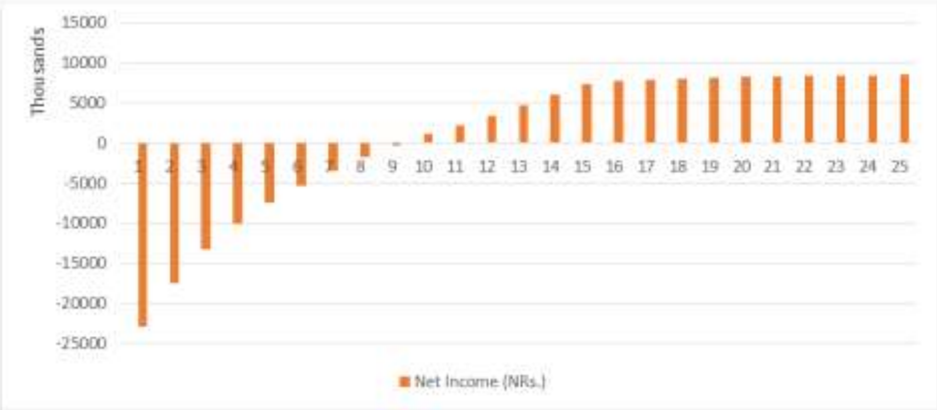

Fig-8: Yearly Net income in 25-year period for scenario 1

Scenario 2

Table-6: Details of financial analysis scenario 2

Financial Mix	100% Debt
NPV	NRs. 154959522
LCOE	3.97 Rs/kWh
IRR	5.35%
WACC	5.8%
Payback Period	12.78 years

In this scenario the IRR is less than WACC, hence the project does not seem to be feasible financially. Further, the sensitivity analysis is performed and it is found that in this scenario in the energy sales rate is greater than 7.6 Rs/kWh than the IRR will be greater than WACC and the project will be financially feasible.

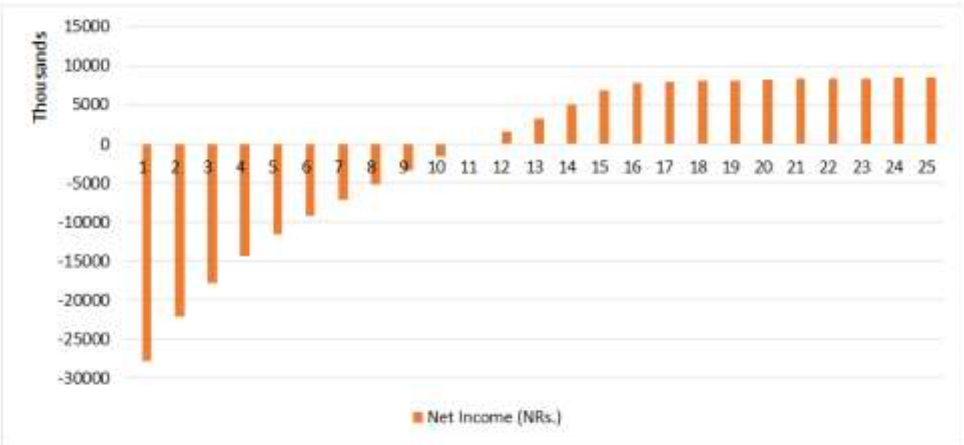

Fig-9: Yearly Net income in 25-year period for scenario 2

CONCLUSION

The average daily global radiation available in the Sikta Irrigation canal was 5.41 kWh/m2.day. For the installation of 1 MW solar PV system above Sikta irrigation canal, 550m south facing stretch of canal was considered. Based on this solar energy potential, the 1MWp grid-connected PV system which is synchronized to grid at 11kV voltage at Kohalpur substation could send electricity to the grid about 1860 MWh/year on average. The designed solar PV system above canal was found technically viable.

The cost estimate of the designed PV system is performed and financial analysis for the 25-year period is done. The LCOE of the designed 1MW solar PV system above canal was found to be NRs. 3.97/kWh. When the financial mix is 100% debt it is found that the payback period will be 12.78 years and for the project to be financially viable the energy selling rate must be greater than NRs. 7.6 /kWh. When the financial mix is 70:30 (70% Debt and 30% Equity) it is found that the payback period will be 12.83 years and due to increase in cost of capital for the project to be financially viable the energy selling rate must be greater than NRs. 10.3 /kWh.

Nomenclature

ETAP: Electrical Transient and Analysis Program
INPS: Integrated Nepal Power System
IRR: Internal Rate of Return
kWh: Kilo-Watt Hour
LCOE: Levelized Cost of Electricity
MWp: Mega-Watt Peak
PV: Photovoltaic
PVsyst: Photovoltaic System Simulation Software
WAAC: Weighted Average Cost of Capital

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