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Techno Economic Analysis of Grid Tied Solar System: A Case Study of Nepal Telecom, Sundhara, Kathmandu

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Abstract

Nepal imported more than one third of the electricity (42.3 %) from India last year, thereby implying major energy security risks. Solar PV injection, therefore, has the power to minimize imports and drive Nepal to be independent in electricity. This research aims to analyze technical and economic parameters of 64.6 kWp grid tied solar PV system installed at Nepal Telecom, Sundhara, Kathmandu, Nepal. The electricity generated from the system is completely utilized at its office and need not require to be fed into the utility grid. Simulation of the system under study was done using PVsyst software with metrological data from NASA-SSE.Technical parameters from the simulation and actual measured generation data were compared. Actual measured generated data were collected from March 2019 to October 2019.The results showed that the system in actual performance produced 6.69 MWh on average monthly, with final yield of 3.38 kWh/kWp/day ,capacity utilization factor of 14.09 % and performance ratio of 0.859. An economic analysis of the system was also performed using actual generated values. It was found the system had discounted payback of 5.2 years, saving NRs.134,000 monthly with IRR of 17.22 % and Levelized Cost of Electricity (LCOE) NRs.17.97/ kWh at a discount rate of 12 %. Hence, grid tied solar systems are ready for commercialization in the country.

Keywords

Grid Tied System – Solar PV – Techno-Economic Analysis

1. Introduction

Nepal is rich in water, solar, wind and biomass resources, but due to the lack of dissemination of innovative technical knowledge and enough financial provision, the country is unable to utilize these resources properly for the benefit of urban and rural livelihoods. In Nepal, around 2.8 % of energy supply come from grid electricity, and is primarily used for lighting purpose only [1]. Hence, most of the people are dependent on other energy sources, such as fuelwood, agriculture residue, coal, and fossil fuels, to cover their needs.

Given that solar is the second most abundant and preferred source of energy for Nepal after hydro, developing the solar PV industry is justifiable. As for other models within solar PV, such as distributed solar home systems (SHSs) and solar micro-grids, Nepal has seen some development in those sub-sectors already, but the impacts from those models were limited. Distributed solar home systems took off in the last decade but the model suffered from severe implementation issues and they were limited to just powering a few bulbs in the rural households. Solar micro-grids turned out to be vastly expensive and unsustainable without 80+% of the total cost in grants. The only other model that can achieve large scale solar PV development is utility-scale solar, as in the case for India today. However, given that Nepal has significant transmission constraints, achieving large utility scale solar becomes less feasible.

Proliferation of grid-tied solar PV solutions would mean that Nepal, currently among the poorest in the world, is able to attain a reliable, diversified energy system that is able to provide power to even the remotest parts of the country, hence ensuring better living standards all of its 30 million people. Nepal's goal is to graduate from the Least Developed Country (LDC) status by the year 2022, and energy is one of the critical ingredients to attain the goal. The government also plans to achieve 99% electrification rate by the year 2030, and it cannot achieve that by relying on hydro plants that can easily take a minimum of five years to construct [2].

2. Grid Tied Solar System

Grid tied solar system simply refers to the solar system that is directly connected to the electricity grid. A Grid-Tied Solar System installed site can use electricity from the solar installation to operate its loads and, if that is not sufficient, any additional electricity required to operate the loads comes from the grid. In case the site does not use all the electricity from the solar system as it is generated, the surplus goes into the grid for the utility to pass on to other customers. A Grid-Tied Solar System mainly has two components:

1. Solar PV Panels that generate electricity when sunlight strikes them.
2. An electronic device called an inverter that converts the direct current (DC) electricity from the solar panels to alternating current (AC) that is synchronized with that of the grid.

Apart from these components, there are other minor components such as switches and fuses that allow each of the two major components to be completely isolated when repairs are needed, and protect the components from damage due to short circuits or lightning.

2.1 World Scenario of Grid-Tied Solar System

The capacity of grid-tied solar systems is rising more quickly and continues to account for the vast majority of solar PV installations worldwide, although demand is also expanding for off-grid solar PV systems [3].Particularly with the policy/use pattern transition from Feed-in Tariffs (FITs), net metering to self-consumption, decentralized (residential, commercial, industrial rooftop systems) grid-tied applications have faced challenges to maintain a roughly stable global market (in terms of capacity added annually) since 2011 [4].Contradictory to this, centralized grid-tied large scale solar PV projects have comprised a significant rising share of annual installations-particularly in emerging markets-despite grid connection challenges, and now represent the majority of annual installation [5].The main drivers for this include increased use of tenders and availability of low cost capital. According to one estimate, an average grid-tied solar project size in early 2016 ranged from 3 MW, 11 MW, 45 MW, 64 MW in Europe, North America, Africa and South America respectively.

In 2016, number and size of large scale grid-tied solar PV plants continued to grow around the world. By the end of 2016, at least 164 (up from 124 in 2015) grid-tied solar PV plants of 50 MW and larger were operating in at least more than two dozen nations with Israel, Jordan, the Philippines and the United Kingdom joining the list during the year [5]. The combined capacity of plants on 50 MW and larger that came into operation in 2016 was more than 5.9 GW [6].Among these, China's Yanchi project in Ningxia successfully became the world's largest plant with 1 GW capacity [5].

Domestic and international organizations based in China, Europe, India, North America and elsewhere invested heavily in solar PV during 2016 [7].New projects came into operation in Australia, Europe and the United States [8].In Japan, an estimated 45MW of community-owned solar PV came into operation by the end of 2016. Increasingly in Australia and the United States, utilities and other energy companies are developing "community" projects to retain existing customers and attract new ones.

In electricity generation in several countries, solar PV has a substantial share. In 2016, solar PV accounted for 9.8 % of net generation in Honduras and met 7.3 % of electricity demand in Italy, 7.2 % in Greece and 6.4 % in Germany. At least 17 countries (including Australia, Chile, Honduras, Israel, Japan and several in Europe) had enough solar PV capacity at end-2016 to meet 2 % or more of their electricity demand [5].

2.2 Grid-Tied Solar System in India

The Ministry of New and Renewable Energy (MNRE), Government of India has announced an ambitious solar target of 100, 000 megawatts (MW) installed capacity by 2022, of which 40,000 MW of solar photovoltaic (PV) systems are to be installed on rooftops [9]. There have been several efforts at the policy, regulatory and implementation levels for solar rooftop deployment in India, For a long time, the country witnessed solar installations with the help of Government funding, which has now started evolving to various public-private partnership (PPP) and private sector-based models. With dramatic reduction in PV prices over the last couple of years, an era of 'grid-parity' has been reached, where the cost of solar electricity is competitive with retail electricity tariffs in many cases. This presents a whole new opportunity for the country, the sector and the market. However, in order to realize widespread solar rooftop deployment opportunities, the implementation process for each stakeholder needs to be clear and simple.

2.3 Grid Tied Solar System in Nepal

In the context of Nepal, the grid tied solar system is in the starting phase. Few attempts have been made in this sector like 1 MW system at Singha Durbar, Kathmandu, 680.4 kW at Ministry of Water Supply, Sundarighat, 100 kW system at Nepal Electricity Authority,Kharipati, 1 kW system at Centre for Energy Studies, Institute of Engineering, Pulchowk- all these attempts have been made in the form of donation,aid,grant or for academic research purpose. This system of Nepal Telecom is first commercial installation in telecom sector in Nepal and its technical and economic success can open new opportunities in various other commercial sectors like schools, hospitals, hotels, banks, industries.

3. Methodology

After thorough review of literatures, Nepal Telecom Sundhara was considered for case study of grid tied solar system because it was located at the centre of Kathmandu valley and most probably first commercial Telecom institution to have installed grid tied solar system. A complete set up of actual solar panels installed at site was designed in software PVsyst V6.84 in order to give actual parameters to the software as far as possible. Simulation results were obtained thereby. In order to compare simulation results with actual performance, generation data were received through remote monitoring device and was also verified at site with inverter readings. With measured generation data, performance parameters were computed. Finally, comparison, analysis and discussions were made for simulated and measured technical parameters. Economic analysis of complete PV system was also performed using Microsoft Excel.

4. System Description

The 64.6 kWp grid tied solar system under study consists of 190 identical Vikram mono solar panels, each rated 340 kWp at Standard Temperature Conditions. There are all together 10 strings in parallel. Each string consists of 19 panels in series. All 10 strings are connected to single 80 kW Delta grid-tied inverter.

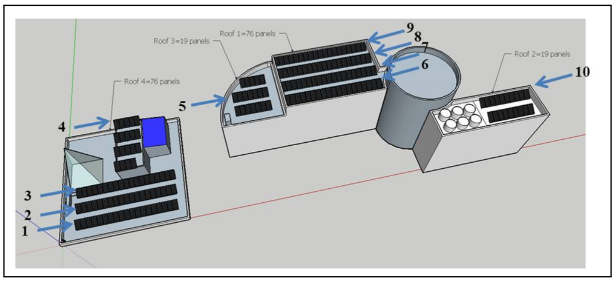

Figure 1: System layout at site with string numbering

The DC output from solar panels is inverted by inverter and then it is sent to control panel of the site where it is joined by utility grid line and diesel generator. While supplying electricity to the load, solar electricity is first prioritized and insufficient quantity is drawn from utility grid line. In case, grid line goes off, diesel generator automatically comes into operation and becomes reference source for solar system operation. Total capacity of solar system is 64.6 kWp while load capacity of site is at least 500 kWp throughout the day. Hence, electricity produced by solar system is entirely consumed at the site and need not require to be fed into the grid. Solar panels are arranged in four roofs of the site building.

5. Definitions of Technical Parameters

The 64.6 kWp grid tied solar system was simulated in PVsyst V6.84, and technical parameters for the system and its components have been established by the International Energy Agency (IEA) Photovoltaic Power Systems Program and are described in IEC standard 61724 [10]. Site of the solar system was situated at geographical co-ordinates of 27.7E, 85.3N at a height of 1289 m above the sea level. The tilt angle was 30 degrees and azimuth angle 0 degrees. The solar radiation data was taken from NASA-SSE satellite. The major technical parameters are final yield, performance ratio (PR) and capacity utilization factor (CUF).

5.1 Final Yield (YF)

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. The final yield is calculated as:

$$\text{Final Yield} = \frac{\text{Actual Energy From Plant(kWh)}}{\text{Total Nameplate DC Capacity(kWp)}} \tag{1}$$

It is often denoted by Yf.

5.2 Performance Ratio (PR)

The performance ratio is the ratio of actual to theoretically possible energy output. It is a measure of the quality of a PV plant that is independent of location and it therefore often described as a quality factor.

$$PR = \frac{\text{Actual Energy From Plant(kWh)}}{\text{Calculated Nominal Plant Output(kWh)}} \quad (2)$$

The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. A well-efficient solar plant should have Performance Ratio in the range of 80 % or above.

5.3 Capacity Utilization Factor (CUF)

The performance of a PV power plant is often denominated by a metric called the capacity utilization factor. It is the ratio of the actual 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.

$$CUF = \frac{\text{Actual Energy From Plant(kWh)}}{\text{Plant capacity(kW)} \times \text{Available theoretical hours(h)}} \quad (3)$$

A study was done at a solar park in Spain to evaluate the average annual performance ratio which is found at 0.67 with a capacity factor of 15.27 % [11].The capacity utilization factor of a fixed tilt PV plant in Nepal will typically be in the region of 20 %. This means a 5 MW plant will generate the equivalent energy of a continuously operating 1 MW plant.

6. Simulation Using PVsyst

The array matrix was defined in PVsyst, panel and inverter installed at site were selected from PVsyst database and thus, a system of 64.6 kWp was simulated. Details of solar panel parameter used were:

Table 1: Parameters of Solar Panel

SN	Description	Values
1	Pmax	340Wp
2	Vmpp	37.98V
3	Impp	8.98A
4	Voc	47.1V
5	Isc	9.42A
6	Efficiency	17.52 %
7	Dimensions	1956X992X36 mm

Similarly 190 number of Vikram Solar Model SOMERA VSM.72.340.03.04 were used. All panels were connected to single Delta 80 kW (Model M88 H) grid tied inverter. This is high efficient on-grid MPPT inverter with inbuilt charge controllers. The array was designed in PVsyst as per actual set up, i.e. there were 4,1,1,4 (total=10) number of strings in Roof 1,2,3,4 respectively. Each string consists of 19 panels in series. All 10 strings were connected to single inverter.

Simulation showed following results:

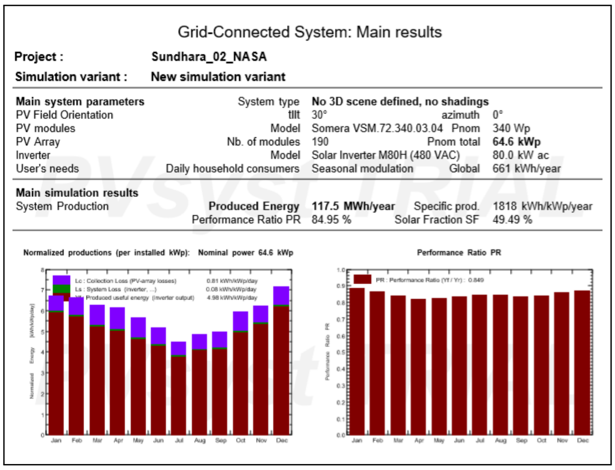

Figure 2: Simulation Results from PVsyst

Thus simulation of the system in PVsyst showed that 117.5 MWh energy could be generated annually, useful energy produced/final yield is 4.98 kWh/kWp/day and annual performance ratio is 84.95 %. It also showed collector loss (PV-array losses) would be 0.81 kWh/kWp/day and system loss would be 0.08 kWh/kWp/day.

7. Results and Discussions

Technical Analysis

This 64.6 kWp grid-tied solar system came into operation from March 2019. Actual measured generation was studied from March to October of the same year during research period of this study.

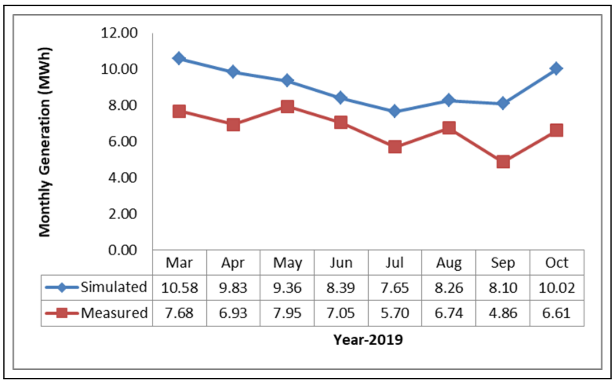

Figure 3: Simulated and Measured Monthly Generation

Figure 3 shows the monthly variation between simulated generation from PVsyst and measured energy generation that can be utilized at the site. In Nepal, November to February is winter and March to October is summer. However within summer, from mid-June to mid-August is monsoon season. Both simulated and measured generation profile support this, as it can be observed, generation is comparatively high from March to June while from July to August, generation is relatively low. Measured generation during study period for months March, April,May and June was found to be 7.68 MWh, 6.93 MWh, 7.90 MWh and 7.05 MWh respectively.Similarly, measured generation for July, August, September and October were found to be 5.7 MWh, 6.74 MWh, 4.86 MWh and 6.61 respectively. On average from March to October, measured monthly system generation was 6.69 MWh and simulated was 9.02 MWh.Low generation during July and August could be explained as these fall into monsoon season, thereby receiving less solar radiation. However, measured generation for September was also low, in fact, lowest among the study period. This could be explained from the fact, monsoon in 2019 in Nepal was bit different compared to previous years as monsoon is generally supposed to conclude by mid-August, however in 2019, it continued till end of September. This shows while designing solar PV systems, climate variation patterns should be also considered to optimize outputs from the systems. This was complemented by the variation in simulated and measured generation figures also.

7.1 Final Yield

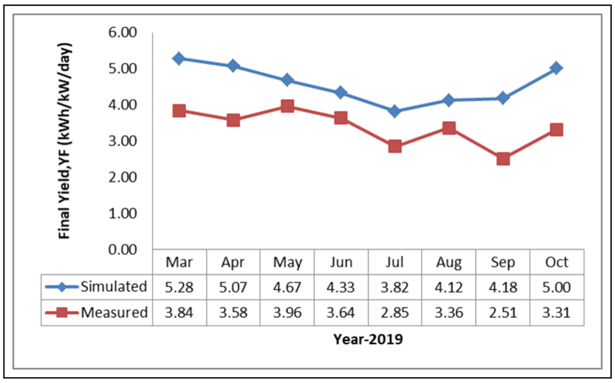

Figure 4: Simulated and Measured Final Yield Comparison

Highest value of measured final yield obtained was 3.96 kWh/kW/day in May while the same value in simulated was 5.28 kWh/kW/day in March. Similarly lowest value of measured final yield obtained was 2.51 kWh/kW/day in September while simulated value had lowest reading of 3.82 kWh/kW/day in July. On average, during the study period from March to October, measured final yield was 3.38 kWh/kW/day and simulated final yield was 4.56 kWh/kW/day. This shows simulated values were relatively higher than measured ones.

7.2 Capacity Utilization Factor

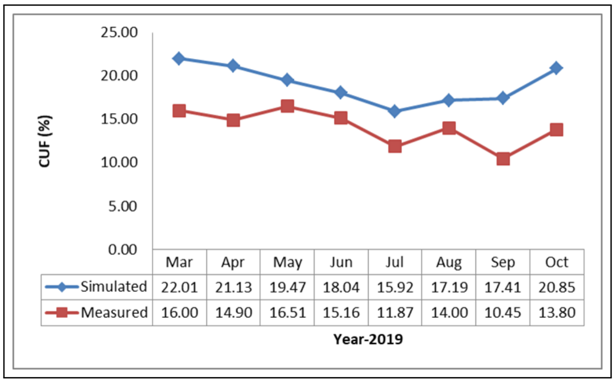

Figure 5: Simulated and Measured CUF comparison

Fig. above shows measured capacity utilization factor (CUF) of the solar system under study varied from 10.45% (September) to 16.51% (May). This was mainly because energy generation (162 kWh/day) in September was lowest due to minimum solar insolation (2.93 kWh/kW/day) on solar panels while energy generation (256 kWh/day) in May was highest due to maximum solar insolation (4.65 kWh/kW/day) on solar panels. Similarly simulated capacity utilization factor (CUF) of the solar system under study varied from 15.92% (July) to 22.01% (March). This was mainly because energy generation (247 kWh/day) in July was lowest due to minimum solar insolation (4.34 kWh/kW/day) on solar panels while energy generation (341 kWh/day) in March was highest due to maximum solar insolation (6.10 kWh/kW/day) on solar panels. During the study period, average measured and simulated CUF were found to be 14.09% and 19.00% respectively.

7.3 Performance Ratio

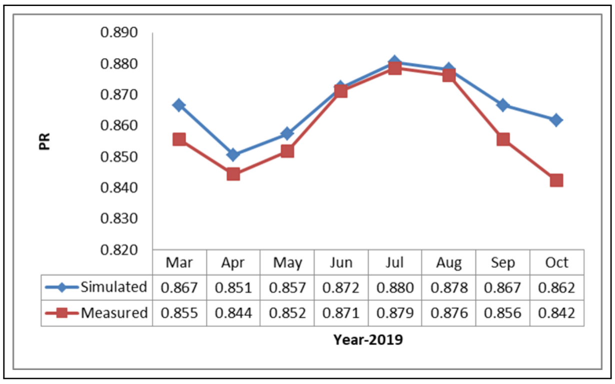

Figure 6: Simulated and Measured PR comparison

Figure 6 shows simulated PR has highest value of 0.880 in July while measured PR has highest value of 0.879 in July. Similarly, simulated PR has lowest value of 0.851 in April while measured PR has lowest value of 0.842 in October. On average, during study period, simulated PR was 0.867 and measured PR was 0.859.

Table 2: Summary of Technical Analysis

Description	Simulated	Actual
Monthly Generation,MWh	9.02	6.69
Fina Yield,kWh/kWp/day	4.56	3.38
CUF(%)	19.00	14.09
PR	0.867	0.859

7.4 Economic Analysis

For the economic analysis, all product cost, transportation cost, custom tax, VAT, system degradation factor has been considered. Assumptions made for analysis were: project life as 20 years, discount rate 12 %, 1 % yearly degradation in system output and need of new inverter after 10th year. Land cost was not considered since it was installed at roof of the site. From the economic analysis using Excel with gross investment of NRs.7,500,000 for 64.6 kWp system, following results were obtained.

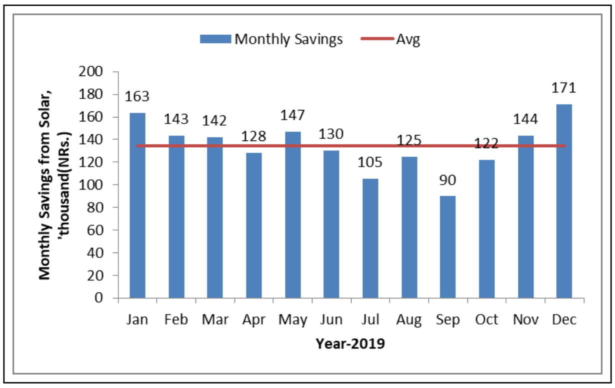

Figure 7: Monthly solar savings

Figure 7 shows monthly savings from 64.6 kWp grid tied system at site. Although measured generation values were available from March to October , values of other months were projected considering loss factor from simulated values from PVsyst. To calculate solar saving, electricity price of Rs.18.5/kWh has been considered as being charged at Nepal Telecom, Sundhara,Kathmandu office. This electricity cost is relatively high compared to other sites in Nepal.This is because of the sensitivity of the site, main office of Nepal Telecom which controls all of the mobile,landline,international calls- site has been provided with dedicated feeder line. Calculations have been also done showing the scenario at regular rates of electricity in Nepal.

Figure 7 also shows on average, system would be saving NRs.134,000 per month, thereby making it about NRs.1.60 million annually.

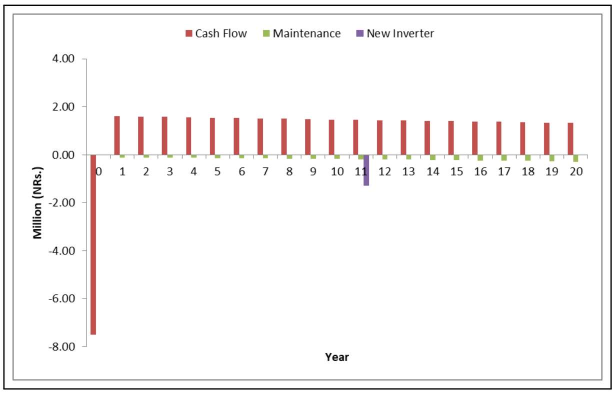

Figure 8: Cash Flow

Figure 8 shows the cash flow of the system. It has been assumed system output will decrease by 1 % every year, maintenance cost for first year would be 1.5 % of investment cost and thereafter it would increase by 5 % every year. In the beginning of 11 year, a new inverter has been added. Since this system is new and although manufacturers guarantee long term running of their products, with a conservative approach of new inverter might be needed to replace after 10 years, price of one new unit has been added.

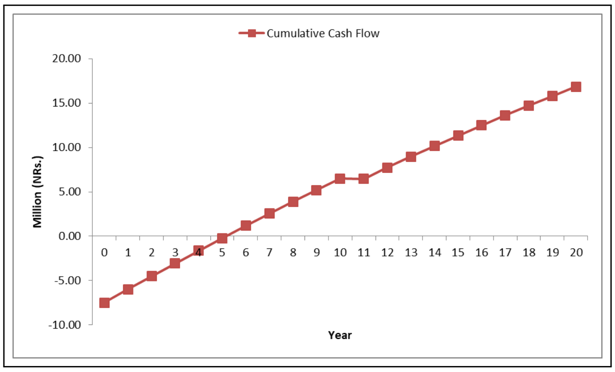

Figure 9: Cumulative Cash Flow

Figure 9 shows cumulative cash flow over the project life span of 20 years at a discount rate of 12 %.This shows discounted payback of the system would be within 5.2 years of operation.

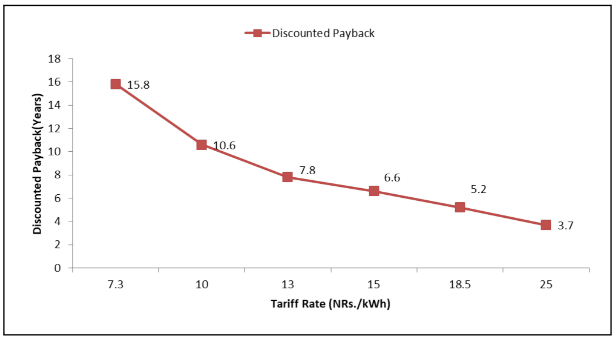

Figure 10: Discounted Payback at different tariff rates

Figure 10 shows discounted payback for Nepal Telecom at NRs.18.5/ kWh would be within 5.2 years. However, at Nepal Government's current policy of NRs.7.30/kWh, it would take more than 15 years to achieve discounted payback. Similarly NRs.10/kWh and NRs.13/kWh represent household and commercial sectors respectively. Further, LCOE and NPV from the system were also calculated and found to be NRs.17.97 kW/h and 2.06 millions Nepalese rupees respectively. Project looks attractive as discounted payback period is short, NPV is positive, IRR is high and LCOE is competitive.

Table 3: Summary of Economic Analysis

Description	Values
Project cost,(millions NRs.)	7.50
Annual Savings,(millions NRs.)	1.60
Discounted Payback (years)	5.2
NPV,(millions NRs.)	2.06
IRR, (%)	17.22
LCOE (NRs./kWh)	17.97
Project life (years)	20
Discount rate (%)	12

8. Conclusion

From this study, it was found, the 64.6 kWp grid- tied solar system at Nepal Telecom, Sundhara,Kathmandu was generating 6.69 MWh on average monthly during the research period from March to October, 2019. Similarly, measured final yield was found to be 3.38 kWh/kW/day, CUF was 14.09 % and PR was 0.859 during the study period. The system will save NRs.134,000 on average monthly and NRs.1.60 million annually. The system has discounted payback period of 5.2 years and LCOE of NRs.17.97/kWh with a project lifespan of 20 years at a discount rate of 12 %. Hence it can be concluded that grid tied solar system is technically and economically ready for commercialization in Nepal.

9. Recommendation

Further study needs to be carried out taking whole year data in consideration in order to have better understanding of the performance of the system. One another aspect that is yet to be considered in this study is the impact of dust on the output of the system. Finally, it would be interesting study to compare results of this system with the results of some other grid-tied system installed at different sites.

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