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Design and simulation of solar roof-top projects for an energy self-reliant university campus

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Abstract. A University campus becoming self-reliant in terms of electricity generation is always important. The power requirement of a University campus is mainly for its academic blocks for different departments. The laboratories, libraries, and hostel facilities also require continuous power needs. Conventionally, the electricity needs are met utilizing the power received from the local utility and the University will be paying for it based on the tariff fixed by the local regulators and agreed by the utility. It is proposed to install Solar Roof-top PV power plants in shade-free rooftops of the buildings inside a University campus to offset the University's electricity needs and to make the University self-reliant in terms of electricity generation and consumption. This integrated and comprehensive solar project is intended to reduce the carbon footprint of the University and aiming for a carbon-neutral campus. Detailed feasibility studies have been conducted for installing solar roof-top power plants in the selected building roof-tops of the University. Based on the feasibility study, design and simulation have been carried out for a total 1.6MWp capacity of solar roof-top projects to completely offset the total electricity needs of the University based on the current electricity consumption patterns. The design and simulation are accomplished utilizing PVsyst software and the economic and environmental analysis has been carried out utilizing RETscreen software for arriving at the results.

Keywords: Solar PV; Self-Reliance; Solar Roof-Top; Simulation; Carbon-Neutral; Green Campus.

1. Introduction

Renewable energy sources are becoming a prominent energy source globally, especially in the last decade [1]. Solar energy is the most prominent renewable energy source and is replacing fossil fuel generations at a great pace worldwide [2]. The cost of solar power has reduced considerably in the last

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decade bringing more and more National Governments are embracing renewable and affordable resources with aggressive policy measures to cope up with the Paris Agreement regulations regarding climate change. A lot of countries have set targets for achieving 100% renewable energy-based generation [3].

Solar Photovoltaic power has reached a cumulative capacity of 627GW in 2019 with China leading in the case of total installations followed by the United States, Japan, Germany, and India. Solar PV is becoming the most sought renewable energy source in the world with a tremendous investment made all over the world. China leading the world as the biggest market in the world in terms of total capacity additions of 31.1GW followed by United State with 13.3GW and India in third place with 9.9GW [4]. International Renewable Energy Agency (IRENA) predicts that the total installation cost of solar PV projects would continue to decline in the next three decades. This would make solar PV highly competitive in many markets, with the average cost falling in the range of USD 340 to 834 per kilowatt (kW) by 2030 and USD 165 to 481/kW by 2050, compared to the average of USD 1 210/kW in 2018. Solar PV power plants are being installed worldwide, mainly in two forms:

1. Solar Roof-tops for residential purposes, industrial purposes, and for commercial purposes[5].
2. MW scale solar farms mainly feeding bulk power to the utility [6]

Among the above categories, solar roof-tops are decentralized power generating systems that can be installed with limited time and easiness. Academic institutions are generally holding large shade-free roof-tops usually eligible for installing solar PV plants. Power can usually be evacuated to the utility grid terminal in the building itself reducing the cost of power evacuation infrastructure and also reducing transmission losses [7].

This paper discusses an integrated and comprehensive approach for installing solar roof-top PV plants to make a University self-reliant in terms of electricity generation. This aims to make the University carbon-free in terms of electricity generation and intended to become a carbon-neutral campus [3]. Karyavattom University Campus under the University of the South Indian State Kerala has been selected for the proposed study.

2. Methodology

2.1 Site details

A site visit has been conducted to assess the technical feasibility of the site to get precise inputs for the technical design of the proposed PV Power Plant. The details are:

Table 1. Site visit details.

Site Name	Kariavattom Campus of the University of Kerala
Roof-top	Roof-top of the Dept. of Geology
Ownership	University of Kerala
District	Thiruvananthapuram
State	Kerala
Latitude	080 33‟ 54.143‟
Longitude	760 53‟ 14.707”
Roof -top Area available	10634 square meters

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The methodology involves:

1. Feasibility study at the University by assessing shade-free roof-tops for installing the roof-top PV plants[8].
2. Design and Simulation of the project utilizing PV Syst Software [8]
3. Economic and Environmental Analysis of the project utilizing RETScreen software [9].

Figure 1. Google earth map of the proposed university campus.

2.2 Feasibility study conducted at the university

The feasibility study is an important step for any solar PV project to succeed [8]. Design, simulation, and economic analysis of a solar photovoltaic system were conducted by Shukla et al. [7]. Primary data was collected by visiting the Kerala University Camus. The various electrical loads operating in these facilities present a peak power demand of around 450 kVA and off-peak demand of around 150 kVA. Thus, the average daily electricity consumption on campus is around 6 MWh. Electrical load in the campus increases by about 10% annually, there is a need to have sufficient power facilities to meet up the future demand as well. Since the campus is having various buildings with sufficient availability of shade-free rooftops, solar power generation is an excellent option for power system management and to meet the peak load demand. At present the entire electric power requirement is supplied by the KSEB through an 11 kV substation located within the campus and from a 100kWp solar power plant is installed on the roof top of Golden Jubilee Building in 2015.

Following buildings were surveyed as part of the feasibility study for installing Roof-top PV power plants:

Table 2. List of buildings selected for solar roof-top PV plants.

Sl. No.	University Building	Area (sq.m)	Estimated Power Generation (kWp) (Assuming 8 sq.m for 1kWp)
1	Dept. of Biochemistry	758.54	100
2	Dept. of Chemistry	1031.55	130
3	Dept. of Computer science(New)	238.78	30
4	Dept. of Computer science(Old)	606.45	80
5	Golden Jubilee building	1883.78	240
6	Dept. of Future studies	1218.75	150
7	SICC building	706.92	90
11	Dept. of Environmental Science (New)	421.28	50
13	Dept. of Environmental science(Old)	1322.8	170
14	Dept. of Malayalam and Tamil	1129.33	140
15	Dept. of Commerce	1315.65	170
16	Library Building	400.24	50
17	ONV Memorial Building	1600.46	200
	TOTAL projected capacity		1600kWp

2.3 PVSyst software
PVsyst is a PC software package for the design and simulation of PV systems. The software is developed by the University of Geneva, Switzerland, and is widely used by the solar industry, developers, and academia. It deals with grid-connected, stand-alone, pumping, etc, and includes PV system component databases [10].

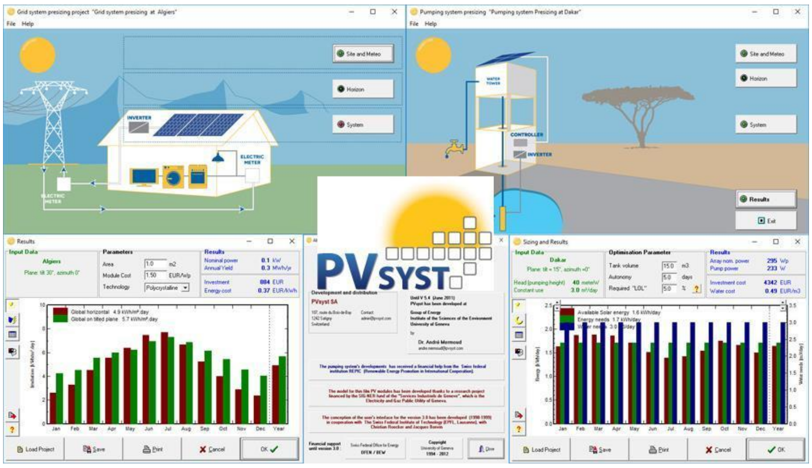

Figure 2. PV Syst software – screenshot.

2.4 RETScreen software
RETscreen Expert integrates several databases to assist the user, including a global database of climatic conditions obtained from NASA satellite data; benchmark database; cost database; project database; hydrology database, and product database. The economic and environmental analysis is to done using this software [10].

Figure 3. RETScreen software – screenshot.

3. Design and simulation of the project and results

3.1 Design of the project utilizing PV Syst software
PV Syst simulation for the project with a total capacity of 1.6MWp is carried out utilizing the freely available solar radiation data of NASA –SSE. The summary of the PV Syst simulation results for the project is given in the following Table 3 & 4 and in Figures 4 & 5. Solar Resource available at the site as a result of the PV syst simulation is given in Table 4.

Summary of the solar generation expected, specific production and the expected PR along with projections for Performance Ratio (PR) and the normalized productions per installed kWp are given as Figure 4. A loss diagram in PVsyst reflects the losses happening to the PV power plant. Loss Diagram obtained as a simulation result of the 1.6MWp Solar Plant at the Kerala University Campus is given as in Figure 5.

Table 3. Summary of the results of PVSyst simulation.

Proposed Installed Capacity	Unit	1600kWp
Project Type		Rooftop
Estimated Annual Energy production	Units (kWh/yr)	2553000 (2.553 million units per year)
Specific Production	kWh/kWp/Year	1596
Performance Ratio (PR)	%	76.7
Solar resource available (GHI)	Wh/m^2	2039.6

Table 4. Solar resource available at the site as resulted from the PVsyt simulation.

Months	GlobHor kWh/m^2	T Amb ^{0}C	Globlnc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	179.8	27.04	198.2	183.1	245.1	241.5	12.28	12.10
February	180.9	27.08	193.3	178.9	237.6	234.1	12.20	12.02
March	211.7	27.22	216.5	200.4	265.2	261.1	12.16	11.98
April	187.2	27.25	183.6	169.2	227.1	223.5	12.28	12.09
May	172.7	27.58	164.1	150.6	205.3	202.1	12.42	12.23
June	144.9	27.05	136.2	124.7	172.2	169.5	12.56	12.36
July	152.2	26.40	143.9	131.9	182.5	179.6	12.59	12.39
August	163.1	26.20	158.5	145.6	199.6	196.4	12.51	12.31
September	172.2	26.31	173.4	159.8	217.2	213.9	12.44	12.25
October	162.4	26.34	169.9	156.6	212.2	209.0	12.40	12.21
November	148.2	26.73	161.1	148.4	201.5	198.4	12.43	12.23
December	164.3	27.08	182.5	168.4	226.7	223.4	12.34	12.15
Year	2039.6	26.86	2081.2	1917.6	2592.3	2552.6	12.37	12.16

Where: GlobHor: Horizontal global irradiation
T Amb: Ambient Temperature
Globlnc : Global incident in coil plane
GlobEff: Effective Global corresponding for IAM and shadings
EArray: Effective energy at the output of the array
E_Grid : Energy injected into grid
EffArrR: Effective Eout array/rough area
EffSysR : Effective Eout system/rough area

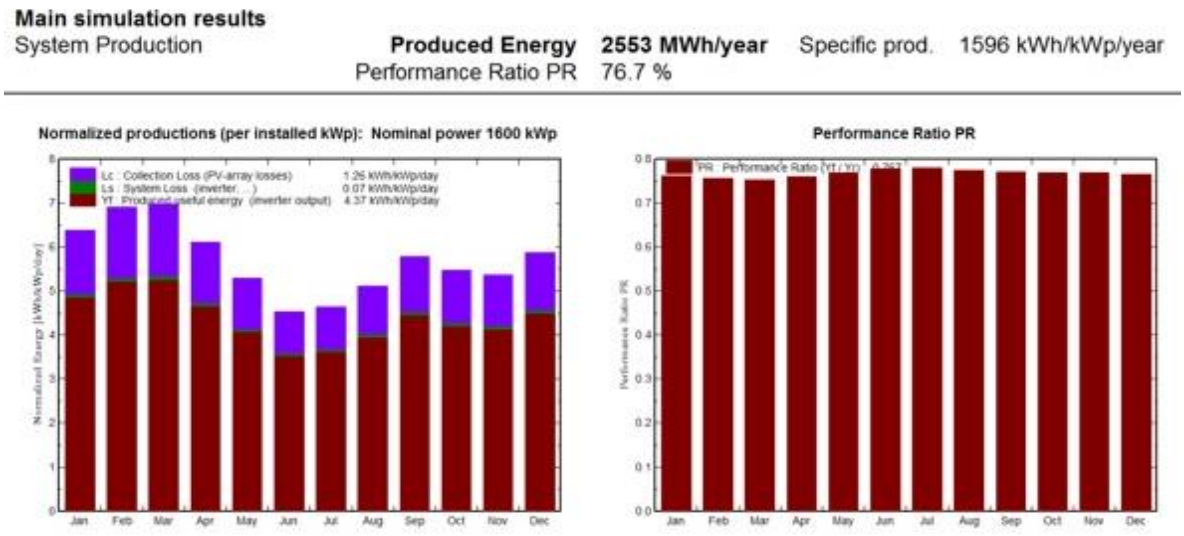

Figure 4. Summary of the Normalized productions (per installed (kWp)).

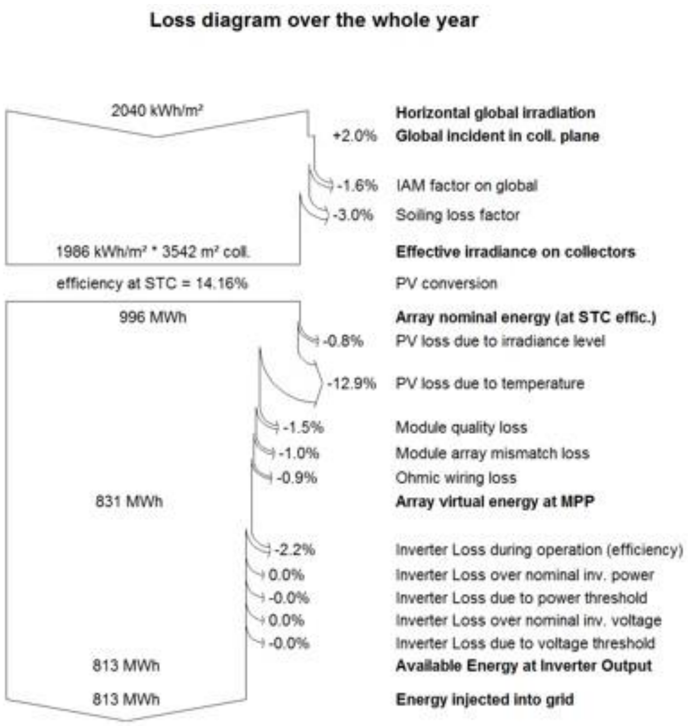

Figure 5. Loss diagram of the PV Plant as simulated for 1.6MWp solar plant.

3.2 Data Analysis to size and define the project

The project size is determined based on the consumption at the university campus and the near future of the addition of any loads. KSEB Ltd. (local public utility) has conducted an energy audit at the site and the report shows that the campus had an energy consumption of 1941497kWh from July 2017 to June 2018. The observation as per the energy audit report of KSEB Ltd is given as in Table 5.

It is observed that the energy consumption of the University from July 2019 to June 2020 was above 22MWh and expected an increase of 10% only in near future. By simulating a 1.6MWp solar power array, using a reputed design and simulation tool PVSyst it is found that we can completely offset this requirement. The area is already available for setting up the roof-top projects as per the feasibility study conducted as given in table 1. From the simulation report, it is clear that the roof-top projects with a total capacity of 1.6MWp can generate 2553 MWh/yr as per the PV syst simulation and this can completely offset the yearly consumption of the University campus in a futuristic perspective. The additional power generated from the PV plants is fed to the 11kV Grid which is going to the utility substation.

Table 5. Energy consumption as part of the energy audit report of KSEBL Ltd.

Sl. No.	Month	Energy Consumption in the Campus (kWh)
1	July 2017	173035
2	August 2017	140375
3	September 2017	148000
4	October 2017	151300
5	November 2017	153200
6	December 2017	174100
7	January 2018	145542
8	February 2018	145542
9	March 2018	157493
10	April 2018	185790
11	May 2018	181250
12	June 2018	185830
	TOTAL	1941497

4. Environmental and economic analysis

Environmental and economic analysis is needed to understand the viability and bankability of the project. Emission reduction studies can bring out figures related to GHG reduction etc. [3]. The design analysis is done using the industry famous software tool RETscreen. The analysis is done in two parts to find out the economic and environmental feasibility of the proposed design [11]. Emmanuel et al; has conducted an economic and environmental analysis of a 10kWp Roof-top PV plant [12]. Solar PV roof-tops are environmentally friendly and are good for mitigating climate change [13]. Fthenakis and Kim investigated the important environmental impacts on solar energy projects and observed its importance in addressing climate change mitigation activities [14]. Gallardo and Karlsson analyzed the PV roof-top plant installed at Galve University in Sweden [15].

4.1. Environmental analysis

Environmental analysis is to find out the annual reduction in GHG emission and thus to determine whether the project is environmentally feasible or not. The analysis gives out the GHG emission reduction summary from where the Gross Annual GHG Emission Reduction can be found out.

The GHG emission reduction as explained above can be achieved by installing Solar Roof-top PV Plants with a total capacity of 1.6MWp. The annual GHG emission reduction is equivalent to various parameters as defined by the RETScreen Software. The analogy as derived by the software is given below as equivalent to the environmental benefits of installing Solar Roof-top PV plants.

Table 6. Summary of GHG emission reduction.

Base case electricity system (Baseline) Country region	Fuel type	GHG emission factor (excl. T&D) tCO2/ MWh	T&D losses %	GHG emission factor tCO2/ MWh
India	All types	0.856	3.0	0.882
Electricity exported to grid	MWh	2,680	T&D losses	3.0
GHG emission				
Base case	tCO_2	2364.3		
Proposed case	tCO_2	70.9		
Gross annual GHG emission reduction	tCO_2	2293.4		

Table 7. Comparison of GHG emission reduction.

The amount of carbon dioxide Mitigation is equivalent to 2,293.4 tonnes	
420	Cars & light trucks not used
9,85,406	Liters of gasoline not consumed
5,334	Barrels of crude oil not consumed
2,293.4	People reducing energy use by 20%
521.2	Acres of forest absorbing carbon
211	Hectares of forest absorbing carbon
790.8	Tonnes of waste recycled

4.2 Economic analysis

The economic analysis has been carried out using RETscreen Software which is developed by the Government of Canada. RETScreen is an efficient software tool used by both industry and academicians. RETScreen is used to analyze the performance of a Solar PV plant of 5MWp capacity in Tamilnadu in India [11]. As per the Govt of India benchmark cost for grid-connected solar power plant, the total initial cost of 1.6MWp solar power plant is 6 crores. The software is used to find out the financial parameters like Payback Period, Internal Rate of Return (IRR), Net Present Value (NPV, Annual Life Cycle Savings, etc. of the solar power plant. The financial parameters found out through RETScreen software are given below in Table 5.

From the RETScreen simulation, it is found that the project has a Simple Payback Period of about 3 years at an electricity export rate of Rs8/- (INR). The project's IRR (equity) value of 33 and the positive NPV of Rs43,08,35,795/- (INR), indicate an economically viable project.

Table 8. Summary of financial parameters obtained for the 1.6MWp project.

Particulars	Unit	Values/ Rs
Electricity Export Rate		Rs 8/-(INR)
Pre-tax IRR–equity	%	33.9
Pre-tax MIRR–equity		8.8
Pre-tax IRR- assets	%	33.9
Pre-tax MIRR- assets		8.8
Simple payback	Yr	2.9
Equity payback	Yr	2.9
Net Present Value (NPV)	INR	43,08,35,795
Annual Life cycle savings	INR/Yr	1,72,33,432
Benefit-Cost (B-C) ratio	-	8.2
Debt service coverage		
GHG reduction cost	INR/tCO_2	-7,514
Energy production cost	INR/kWh	1.57

5. Conclusion

Design and Simulation of the proposed Solar Roof-top Projects with a total capacity of 1.6MWp was accomplished in this paper based on feasibility studies conducted at the University Campus and also utilizing industry-standard software like PV syst and RETScreen. This project will offset the electricity needs of the University Campus and thus helps the campus to become self-reliant in terms of electricity generation for meeting its power needs. The extra power will be fed to the utility grid. The economic analysis brings attractive figures for investment. The project has got simple payback of 2.9 years, a Pre-tax IRR equity of 33.9%, and a Benefit-Cost (B-C) Ratio of 8.2. This project can bring the GHG emission reduction of 2293.6 tonnes of carbon dioxide which is equivalent to 790.8 tonnes of waste recycled per annum, 211 hectares of forest absorbing carbon, 5334 barrels of crude oil not being consumed, 985406 liters of gasoline not consumed, and 420 light trucks and cars not being used. Thus, the proposed solar roof-top project is both environmentally friendly and economically feasible. A University becomes carbon-free in terms of electricity generation when it generates all its electricity needs from renewable energy sources. The University's effort to become self-sufficient in terms of energy is also full filled utilizing PV and its emerging technologies.

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