



Technical Report
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**15kW ROOFTOP PHOTOVOLTAIC SYSTEM ON
MAIN AUDITORIUM BUILDING, PDCU
(AS A PART OF THE NET-ZERO ENERGY DEMONSTRATION PROJECT)**



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Preface

The 15 kW grid-tied photovoltaic system is a component of the Net-Zero Energy Demonstration Project by GERMI. This Project aims at converting the Main Auditorium Building at the Pandit Deendayal Petroleum University (PDPU), Gandhinagar, into a net-zero energy building. It is planned that energy equivalent to the Building's requirements be met using the photovoltaic system installed on its terrace. Subsequent components of this Project include monitoring of energy demand as well as generation of the Building, and further attain the goal through energy efficiency measures and additional energy generation. The Energy and Petrochemicals Department (EPD), Govt. of Gujarat, is the proponent of this Project, and the Project is funded by the Gujarat Energy Development Agency (GEDA).

Executive Summary

Photovoltaics, the direct method of converting sunlight into electricity, has a potential to substantially meet the world's future energy needs. The grid-tied photovoltaic rooftop configuration is a widely accepted model for large-scale solar energy deployment. Such rooftop systems are very simple, and easy to install, operate and maintain, while the accounting for electricity can be done through a dedicated energy meter.

A 15 kW photovoltaic rooftop system (the "Project") is installed on the terrace of the Auditorium Building of Pandit Deendayal Petroleum University (PDU), Gandhinagar. 72 photovoltaic modules of 210W capacity and 14% efficiency are used. Versatile Module Mounting Structures (MMS) are used to mount the photovoltaic modules at an inclination of 25° facing south to maximize the capture of sunlight and consecutive conversion into electrical energy, and are spaced out so that they do not cast any shadows on each other. 3 numbers of SMA Sunny Boy 5000TL grid-tied inverters are used in the Project to convert the DC electricity from strings of photovoltaic modules to AC electricity and feed into the grid. These inverters are up to 97% efficient, and ensure that maximum power is extracted from the photovoltaic modules. An isolation transformer of 18kVA is used between the output of the inverter and the electricity grid; this transformer mainly serves as a protection device for the photovoltaic system. The safety of the photovoltaic system is ensured through the use of appropriate surge protectors, miniature circuit breakers, lightning arresters, and earthing. The cables and connectors used for the Project are of cross-section 4mm², and are of sufficient current-carrying capacity while offering robust weather resistance.

The photovoltaic system is designed with the following configuration, where two strings each comprising of 12 photovoltaic modules are connected to each 5 kW inverter. Further, all the three inverters provide an individual phase resulting into a net 3-phase 15 kW configuration. The output of the photovoltaic system is directly connected into the AC distribution bus of the Auditorium Building.

Table: Photovoltaic system configuration.

Item	Quantity	Corresponding Power (W)
Photovoltaic module	1	210
Modules per String	12	2,520
Strings per Inverter	2	5,040
Inverters per System	3	15,120
TOTAL SYSTEM SIZE:		15 kW

The photovoltaic system has been functional since 14 April, 2011, and consistently providing power into the electrical grid. The 15 kW photovoltaic system has generated **15,504 kWh** of electrical energy up to 12 March, 2012. The average daily output of the photovoltaic system is 46.41 kWh.

Table: Summary of electrical energy outputs for each inverter of the Project.

Period		Inverter 1 (kWh)	Inverter 2 (kWh)	Inverter 3 (kWh)
14-30 April, 2011	Total Output	166.9	171.1	197.6
	Avg. Daily Output	9.8	10.1	11.6
1-31 May, 2011	Total Output	580.0	595.2	611.3
	Avg. Daily Output	18.7	19.2	19.7
1-30 June, 2011	Total Output	515.6	518.3	513.9
	Avg. Daily Output	17.2	17.3	17.1
1-31 July, 2011	Total Output	433.3	434.9	423.6
	Avg. Daily Output	14.0	14.0	13.7
1-31 Aug, 2011	Total Output	321.203	326.86	333.88
	Avg. Daily Output	10.36	10.54	10.77
1-30 Sept, 2011	Total Output	405	405.67	413.08
	Avg. Daily Output	13.5	13.52	13.77
1-31 Oct, 2011	Total Output	504.14	497.43	519.27
	Avg. Daily Output	16.26	16.05	16.75
*1-24 Nov, 2011	Total Output	541.74	553.43	565.72
	Avg. Daily Output	22.57	23.06	23.57
*25 Nov, 2011 to 31 Dec, 2011	Total Output	432.81	455.90	470.23
	Avg. Daily Output	11.70	12.32	12.71
*1-31 Jan, 2012	Total Output	392.17	397.36	417.08
	Avg. Daily Output	12.65	12.82	13.45
1-29 Feb, 2012	Total Output	547.15	567.82	560.28
	Avg. Daily Output	18.87	19.58	19.32
1-12 Mar, 2012	Total Output	233.91	243.80	236.01
	Avg. Daily Output	19.44	20.32	19.67
14 April, 2011 to 12 Mar, 2012	Total Output	5073.92	5167.77	5261.95
	Avg. Daily Output	15.19	15.47	15.75

*There was a problem in communication system for period from 25th November, 2011 to 17th January, 2012, hence for that period cumulative data has been shown in the table.

On the demand side, the Auditorium Building consumes an average of 141.1 kWh per day, which can further be classified into two components, which are (i) daytime energy usage of 72.9 kWh, and (ii) night-time energy usage of 68.2 kWh. The recently recorded and stabilized electricity generation from the photovoltaic system averages at 66.2 kWh, which can cater for either the daytime or night-time load.

The recorded data indicates that a photovoltaic system of net 32 kW capacity is required to make the Auditorium Building at PDU a net-zero energy building.

In addition to energy generation, this photovoltaic system is also used for Solar Technical Workshops conducted by GERMI giving them a unique hands-on opportunity to gain deeper understanding of the technology.

Table of Contents

Contact Information.....	2
Preface	2
Executive Summary.....	3
Abbreviations.....	7
1. Introduction to Photovoltaics	8
1.1 What is Photovoltaics?.....	8
1.2 Advantages and Disadvantages of Photovoltaics	10
1.3 The Grid-Tied Photovoltaic Rooftop System.....	11
2. Photovoltaic System Components	14
2.1 Solar Photovoltaic Module.....	14
2.2 Module Mounting Structure	15
2.3 Grid-Tied Inverter.....	16
2.4 Isolation Transformer	18
2.5 Surge Arrester and Miniature Circuit Breaker	18
2.6 Earthing and Lightning Protection	19
2.7 DC Cables and Connectors	19
3. Overall System Design.....	21
3.1 System Sizing and Electrical Design	21
3.2 Physical Layout.....	21
4. Photovoltaic System Performance.....	24
4.1 Photovoltaic System Output	24
4.2 Power Generation: Daily Profile	26
4.3 Comparison with Building Demand	27
4.4 Other Benefits: Solar Training.....	28
Appendix-I: PV Module Specifications.....	30
Appendix-II: Module Junction-Box Specifications	32
Appendix-III: Module Mounting structure Specifications.....	38
Appendix-IV: Grid-Tied Inverter Specifications.....	43
Appendix-V: Isolation Transformer Specifications.....	46
Appendix-VI: Surge Arrestor Specifications.....	49
Appendix-VII: Miniature Circuit Breaker (MCB) Specifications.....	52

Appendix-VIII: Cables Specifications 54
Appendix-IX: Cable Connector Specifications 60

Abbreviations

A	:	Ampere; Unit of current
AC	:	Alternating Current
DC	:	Direct Current
EPD	:	Energy and Petrochemicals Department, Government of Gujarat
GEDA	:	Gujarat Energy Development Agency
GERMI	:	Gujarat Energy Research and Management Institute
Hz	:	Hertz; Unit of frequency
I_{MP}	:	Current at Maximum Power Point
I_{SC}	:	Short-Circuit Current
kW	:	Kilowatt; Unit of Power
kWh	:	Kilowatt-hour, also commonly known as a 'Unit'; Unit of Energy
mc-Si	:	Multi-Crystalline Silicon
MPP	:	Maximum Power Point
MPPT	:	Maximum Power Point Tracking
MW	:	Megawatt; Unit of Power
PDPU	:	Pandit Deendayal Petroleum University
P_{MAX}	:	Maximum Power Point or Maximum Power Rating
PV	:	Photovoltaics
RIIC	:	Research Innovation and Incubation Centre
SPD	:	Surge Protection Device
V_{MP}	:	Voltage at Maximum Power Point
V_{OC}	:	Open-Circuit Voltage
W	:	Watt; Unit of Power
XLPE	:	Cross-Linked Polyethylene
XLPO	:	Cross-Linked Polyolefin
η	:	Efficiency

1. Introduction to Photovoltaics

1.1 What is Photovoltaics?

Photovoltaics, or PV, is the direct method of converting light into electricity using a device known as a solar cell.

When semiconductors such as silicon are exposed to sunlight, they produce small amounts of electric charge (electrons and holes). A well-designed solar cell separates this charge to form a positive and negative terminal. Hence, these terminals produce a voltage, and when connected to an external circuit, cause a current flow. In this way, a solar cell in the Sun works just like a battery.

Photovoltaic systems can be designed for various applications and varying electricity requirements. Solar cells in the range of milliwatts are used in watches and calculators; the requirements of solar blinkers and lanterns are a couple of watts; street lights utilize photovoltaic systems of a couple of tens or hundreds of watts; rooftop systems are designed in the range of kilowatts; while solar photovoltaic power plants are installed in the range of megawatts.



Calculator: 15 mW.



Lantern: 10 W.



Solar Power Plant: 14 MW.



Solar Roof: 5 kW.



Street Light: 75 W.

Figure 1.1: Photovoltaic systems of varying sizes.