IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified

Vol. 3, Issue 7, July 2016

Techno-Economic Design of 432 KW_P Grid Interactive Rooftop SPV Power Plant at Delhi Technological University (DTU)

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Abstract: With the increasing energy demand annually for Delhi , Solar PV has become a reliable option for electricity generation power deficient state which purchase major share of its power requirement from other starts at higher prices. Also increasing pollution levels has also forced Delhi government to aggressively promote solar power plant especially rooftop segment keeping in view the shortage of land and its relatively higher prices. In this paper the rooftop Solar PV system of 432 KWp has been designed for Delhi Technological University to the reduce grid dependence based on fossil fuels. The main work of this paper involves detailed designing of the Solar system along with array configuration, Mounting Structure, Shadow analysis and economic feasibility. At the end decision is made to install solar rooftop project based on techno-economic feasibly study carried out for DTU PV power plant.

Keywords: Solar PV, Delhi Technological University, 432 KWp, DTU PV power plant.

1. INTRODUCTION

Energy plays a key role in the economic growth of the country. There is a close relationship between the Energy consumption & future growth of a nation. Especially in India, there is a never ending thirst for energy. Energy can be derived from one source to another like traditional sources i.e. wood, cow dung, and biomass, etc or modern sources i.e. coal, water, nuclear energy, etc. But more awareness for environmental friendly energy sources has led to rise of renewable energy sources like solar, wind, tidal, etc which are clean and sustainable for future generations. Solar energy is considered as perfect solution for the need for clean, abundant sources of energy, but solar energy currently provides only 0.01 percent of the total electricity supply needs.

Compared to conventional energy sources, solar power is especially attractive because of the following reasons:-

- Solar power can be easily scaled up from few KW to MW scale in a short period.
- Solar power can be generated on site near to consumers which greatly reduces or transmission costs and associated losses.
- Solar power costs have come down to level of cost associated with conventional energy sources.

In this paper we have designed and estimated performance analysis of to be commissioned 432 kWp grid connected SPV system at DTU rooftop along with its economic feasibility.

2. COMPREHENSIVE DETAILS OF PROJECT

DTU campus has lush green campus spread over 160 Acres in Delhi 432 $KW_{p.}$ Solar photo voltaic grid connected power plant will be installed at DTU rooftops of various buildings like Mechanical engineering department, electrical engineering department and civil engineering department, etc. Major details of the project site are given in following table as follows:-

Table 1:- Project details of DTU plant

PARAMETERS	DETAILS
SITE LOCATION	DTU,DELHI
LATITUDE	28.45°N
LONGITUDE	77.07 ° E
ELEVATION	216 m
SPV SYSTEM LOCATION	ROOFTOP
SYSTEM CAPACITY	432 KW_P
ROOF SURFACE	FLAT
PLANT TOPOLOGY	GRID CONNECTED
PV MODULE TECHNOLOGY	CRYSTALLINE
NO. OF CELLS IN PV MODULE	72 CELLS
TOTAL NO. OF PV MODULES	1440
TILT ANGLE	25°
AZIMUTH	0° (SOUTH)
INVERTER OUTPUT	415 V_{AC} , 3 PHASE
AVERAGE IRRADIATION(kWh/m²/day)	5.27
ESTIMATED ANNUAL GENERATION (kWh)	635677

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3. SYSTEM ARRAY LAYOUT

432 KWp solar power plant will be located at DTU rooftops of various departments in smaller sized plants ranging from 24 kWp to 30 KWp in size at different 17 locations at DTU campus. Each grid connected inverter used will be of 25 KVA rating with string size of 20* 300 Wp modules which all are connected in series to get maximum power voltage of 745 Volts and 5 no. of strings are made which raises the current at 8.74 A in each string. Layout of system array for 432 KWp at DTU is shown in following table:-

Table 2:- System configuration for DTU rooftop solar power plant

Inverter No.	Inverter Rating	Module Rating	String Size	Voc / Vmp	I sc / I mp	Total No. of Strings	Total No. of Modules	Total Rating of Modules
Inv. – (1)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	5	100	30 Kwp
Inv. – (2)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	5	100	30 Kwp
Inv. – (3)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	5	100	30 Kwp
Inv. – (4)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (5)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (6)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (7)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (8)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (9)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (10)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (11)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (12)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (13)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (14)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (15)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Inv. – (16)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	5	100	30 Kwp
Inv. – (17)	25 KW	300 Wp	20	902/745.6 V	8.74/8.05 A	4	80	24 Kwp
Total						**36**	**720**	**432 KWp**

Physical layout of the solar power plant to be installed at DTU rooftop can be made on Google Sketch up software to ideally find the maximum number of arrays that can be installed on rooftop without shading each other and avoiding shades from other nearby constructions. Simulation layout of one of the buildings of the DTU has been made showing various array structures on the rooftop along with shadow analysis as shown in following figure:-

Figure 1:- System layout for DTU rooftop solar power plant

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COMPONENTS OF SOLAR PV SYSTEM

Basic Components for Solar PV systems are:-

- Solar PV Modules
- Grid interactive Inverter along with Data logger
- Module mounting structures
- Energy Meter
- Junction Boxes and Distribution Boards
- Cables
- Earthing and Lightning protection

Number of Modules will be combined to form an array using series and parallel configuration. The strings will be combined into an Array via Combiner Box or Junction Box. The output of the Array Junction Box will be connected to DC Distribution Board. The DC Distribution Board output will be connected to an inverter for conversion to AC Power and make it suitable for feeding loads & transmission to local LT supply. Block diagram of a grid connected solar PV power plant along with various losses occurring at various levels is shown in following figure:-

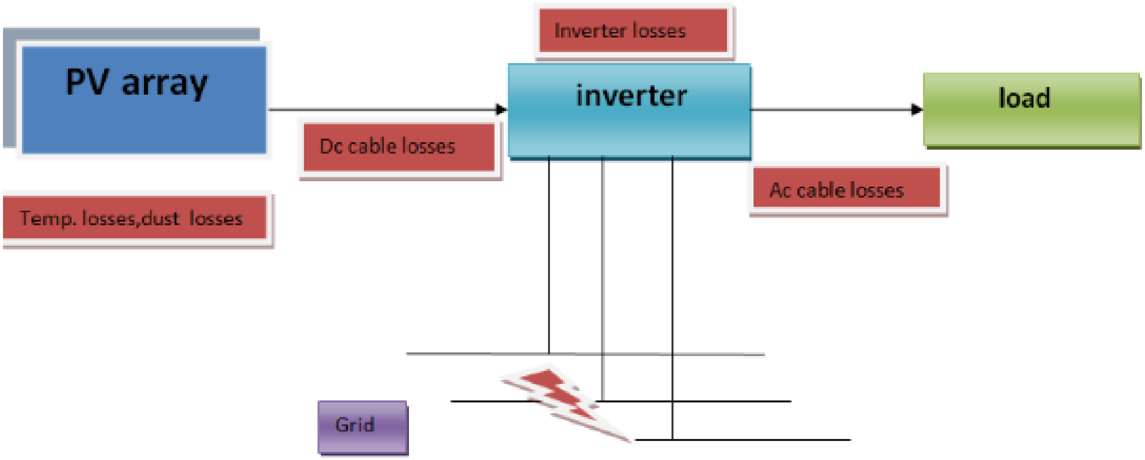

Figure 2:- A typical grid connected SPV system

4. SOLAR PV MODULE

A solar photovoltaic module is a packaged interconnected assembly of solar cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Because a single solar panel can only produce a limited amount of power, an installation will contain several panels. This is known as a photovoltaic array. A photovoltaic installation typically includes an array of solar panels, an inverter and interconnection wiring. Solar panels use light energy i.e. photons from the sun to generate electricity through the photovoltaic effect. The type of SPV Modules used will be of crystalline Silicon type with efficiency of about ≥16 %. Technical specifications of the solar Module used are shown in following table:-

Table 3:- Technical specifications for solar PV module

Attributes	Details
Peak Power P max	300 Wp
Maximum Voltage, V mp	37.28 V
Maximum Current, Imp	8.05 A
Open Circuit Voltage,Voc	45.1 V
Short Circuit Current, I sc	8.74 A
Efficiency	15.72 %
Tc for Open Circuit Voltage	0.052 %/°C
NOCT	44°C +/ - 2°C
Junction Box	IP 65, 3 By Pass Diodes
Dimensions	1979 X 991 X 38 (mm)
Performance Warranty	90 % for 12 yr, 80% for 25 yr

MOUNTING STRUCTURE

A number of PV panels connected in series and in parallel give a DC output for the given incident irradiance. Orientation and tilt of these panels are important design parameters as well as shading from surrounding obstructions. Suitable number of Array frames will be provided. The array frames are made of MS Galvanized/ Aluminum and is protected against the corrosion and other environment impacts. The array frames would be certified for wind and seismic requirements of the area. The array frames are designed for simplicity, low cost and ease of installation at site. The galvanized steel structure provides support for the photovoltaic modules and has longer life and gives them the optimum angle of inclination dependent on the system location. Technical specifications of the solar Mounting structure used are shown in following table:-

Table 4:- Technical specifications for solar module mounting structure

Attributes	Details
Type	Fixed
Tilt	25 °(acc. to location)
Material	Galvanized Iron

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Surface Finish	Hot Dipped Galvanizing
Wind Speed Tolerance	≥ 150 Km/hr
Hardware	All Hardware required for fixing structure and solar modules shall be provided
Foundation	Not required

INVERTER

Solar photovoltaic is DC (Direct current) source. The DC output has to be inverted to the grid alternating current (AC) by a power electronic device referred to as inverter/power conditioning unit. The synchronization happens automatically with available grid voltage & frequency and it starts to feed module output into grid. The second important job of the solar power inverter is to operate the PV system at its maximum power point (MPP) & extract maximum generation. The MPP is defined as the operating point where combined value of voltage & current result in maximum power output. This MPP fluctuates during operation in an interval depending upon the radiation, cell temperature & the cell type and it has to be tracked by the inverter controller unit. The Inverter for the 25 kW SPV power plant will be a grid connect which will be a combined unit comprising of inverter and necessary protections. Technical specifications of the solar inverter used are shown in following table:-

Table 5:- Technical specifications for solar grid connected Inverter

Attributes	Details
Max. DC Power	25550 W
Max. Input Voltage	1000 V
MPP Voltage Range / Rated Input Voltage	390 – 800 V / 600 V
Min. Input Voltage/ Start Input Voltage	150 V / 188 V
Max. Input Current	33 A
No. of Independent MPP Inputs	2
Rated Power	25000 W
Max. AC Apparent Power	25000 VA
Nominal AC Voltage Range	160 - 280 V
AC Grid Frequency / Rated Grid Voltage	50 Hz / 230 V
Max. Output Current	36.2 A
Max. Efficiency	98.1 %

JUNCTION BOX & DISTRIBUTION BOARDS

A Junction Box is a passive device which takes the wires from several arrays and/or solar panels and combines them into one main bus or feed. Fuses (and fuse holders) or breakers can be included as per requirement. The Array Junction Box will be used to combine the strings from the PV array to one point to avoid complex cabling & losses. The junction box will comply IP 65 standard. The enclosure for the junction boxes and distribution boards will be dust and vermin proof. All necessary safety protections will be provided in the enclosure. All the circuit breakers, connectors etc will be as per standards.

The output from each Combiner Box can be fed to a DC distribution board. DC distribution board is designed to isolate the solar module part from the inverter for maintenance purpose.

The AC Distribution Board is kept between inverter & grid. The purpose of AC DB is multifold. First, it protects the inverter from any surge coming from the grid & improves the MTBF (Mean time between failures). Secondly, it blocks the free flow of fault current and it is used to isolate inverter from the grid for maintenance. Technical specifications of the solar junction boxes and combiner boxes used are shown in following table:-

Table 6:- Technical specifications for Junction box and Distribution Board

Junction Box & Distribution Boards	
Type	Weather proof, Dust & Vermin proof
Cable Glands	Suitable Size
Terminals	Connector terminals for Copper cable and Bus Bar

CABLES

In order to have minimum losses in the solar photovoltaic power plant, cable selection is a critical activity of the design. The size of the cable is very carefully selected ensuring very limited power & voltage drop. The selection of cable is done considering the short circuit current that can flow through cables. The cables used are multi strand Copper cables. The cables exposed to environment are double sheathed –UV protected ones. All the cabling will be carried out as per the standards. Technical specifications of the solar cables used are shown in following table:-

Table 7:- Technical specifications for Solar cables

Attributes	Details
Conductor	Multi stranded high conductivity Copper
Insulation / Sheath	PVC / XPLE Insulated
Cable Lugs for termination	Provided in Installation kit
Temperature Range	-10 °C- 70 °C
Certifications	650/1.1 KV grade as per IS 694 & IS 1554

EARTHING & LIGHTNING PROTECTION

The earthing of all outdoor equipment & provision of associated earthing systems, electrodes & connections will be as per IS 3043 standards. Earth electrodes will be provided throughout plant areas along with the main earth grid. Adequate number of earth electrodes are provided so that the total earth grid resistance is less than 5 ohm & hence the possible fault current is taken care of. Earth

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electrodes will be made up of earthing rod of 17 mm diameter and 3 meters long. The earth electrodes will be provided in earth pits. The earth pit will be of two types – treated with earth links & untreated.

The main buried grid conductors will be connected to all the earth electrodes to form a total earth grid. Galvanized steel flats will be used as per approved design. The frames of all electrical equipment & structural work will be earthed by connection to the earth grid by branches of same cross sectional area of earth grid. Lightning protection will be as per IS Standards. Vertical air termination of 40 mm diameter and 3 meter long will be provided above highest point of array to ensure full radius protection to array.

SYSTEM SINGLE LINE DIAGRAM (SLD)
Electrical layout of the solar power plant can be shown in the form of single line diagram which shows the flow of power from on e component to another through various components. Solar pv modules are connected in series parallel arrangement to make arrays which are earthed via earthing rods.

All strings are connected to grid connected inverter pv input and ac output from inverter is connected to distribution board via MCB and then to three phase meter via MCCB. Then AC three phase output is connected to LT panel and is sent to transformer to step up voltage so that solar power plant can be connected to HT panel and DTU distribution system. Following Single line diagram is shown in following figure:-

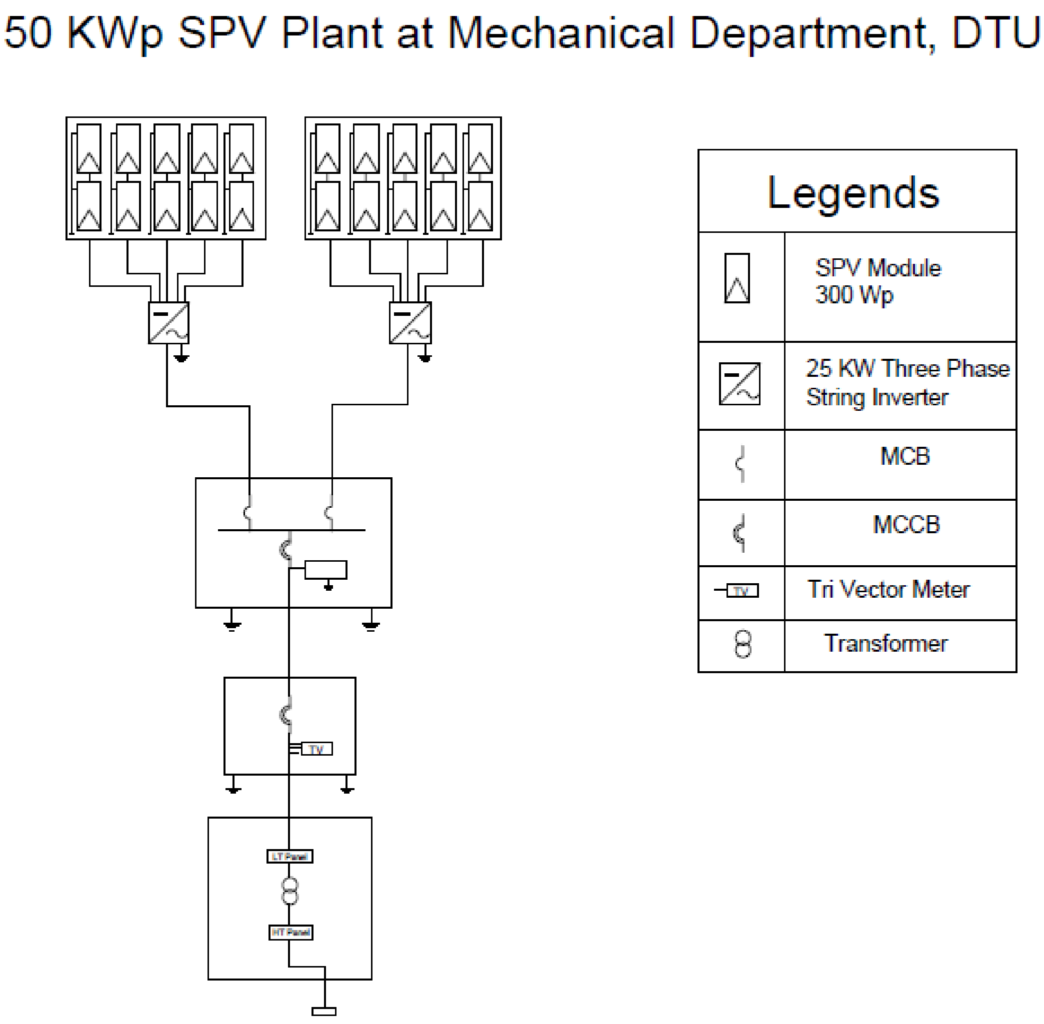

Figure 3:- Single line Diagram for DTU solar rooftop power plant

SHADING ANALYSIS
Distance between two consecutive solar PV arrays should be kept such that shadow of one array mounting structure do not falls on other mounting structure. This shadow analysis is done on Google sketch up software for 23rd Dec for which sun altitude is lowest in the sky for the year which will yield lowest shadows. Hence distance is maintained minimum to obtain minimum shading losses to keep annual generation of power high. Simulation of shading analysis for 23 rd December is shown in following figure:-

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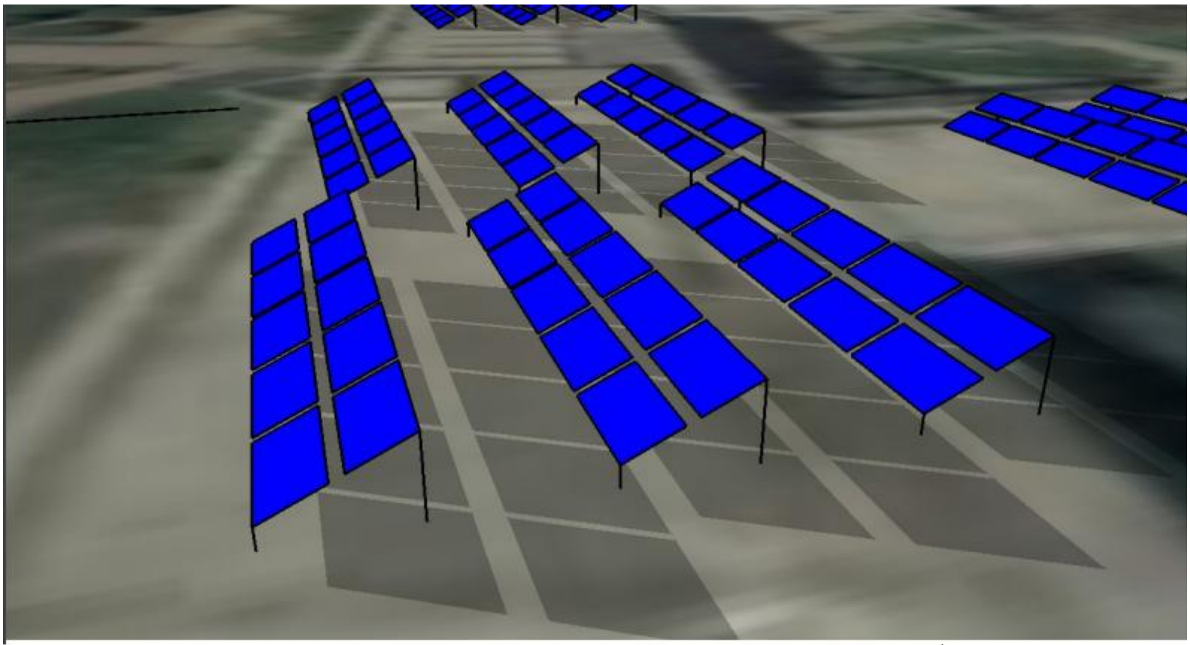

Figure 4:- Shadow Analysis for DTU solar rooftop power plant at 23rd Dec

ESTIMATION OF ANNUAL POWER GENERATION

PV power plant works on GHI whose estimation is most important factor for estimating annual generation of power and plant financial feasibility. Ministry of New and Renewable Energy (MNRE) has set up solar radiation ground monitoring stations all across India for Measuring GHI, DNI and equivalent sunshine hours for particular site. Average Global Horizontal Irradiation (GHI) for Delhi region comes out to be in range of 3.3 KWh/m2/day to 7 KWh/m2/day. Monthly average irradiation on ground for the site is given in following table:-

Table 8:- Annual Solar resource assessment

MONTH	AVERGAE MONTHLY GHI (kWh/m^2/day)
JAN	3.45
FEB	4.76
MAR	6.09
APR	6.83
MAY	7.03
JUN	6.34
JUL	5.57
AUG	5.41
SEP	5.44
OCT	5.04
NOV	3.99
DEC	3.30
ANNUAL AVERAGE	**5.27**

With annual average GHI values of 5.27 KWh/m2/day and assuming 310 clear sunny days for Delhi region, monthly generation potential for 432 KW system is estimated by multiplying system capacity with average daily GHI values and number of clear sunny days in a year which comes out to be 635677 KWh annually or 1470 KWh annually per kW of solar PV system installed at Delhi. Monthly power generation potential calculated month wise is shown in following table:-

Table 9:- Annual power generation potential

MONTH	ESTIMATED GENERATION (kWh)
JAN	42803
FEB	49458
MAR	63651
APR	64476
MAY	59839
JUN	52764
JUL	47698
AUG	50851
SEP	54418
OCT	58009
NOV	48102
DEC	43728
ANNUAL AVERAGE	**635677**

ECONOMIC FEASIBILITY OF 432 KW PV SYSTEMS AT DTU

After estimating the generation potential for PV power plant, financial feasibility is done by calculating payback period for the system which should be low as possible. PV Modules used are of Vikram or Renesola make of multi crystalline based silicon technology, Inverters used are of SMA, Delta or Sukam with data loggers, mounting structure used are of corrosion resistant hot dip galvanized iron and other balance of systems are of reputed make. Basis of estimation of annual benefits is calculated on

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electricity process paid by the DTU per KWh consumed. Following table shows the economic analysis of the 432 KW power plant by showing cosy incurred due to various components of plant:-

Table 9:- Economic Feasibility OF 432 KW_p Power plant

Component	**Quantity required**	**Total cost**
Module cost @ Rs 34/watt p	1440 modules of 300 W_p each	Rs 14688000/-
Inverter cost @ Rs 10/watt	17 inverters of 25 KVA rating each	Rs 4250000/-
GI Structure and civil work @ Rs 110/kg	1 complete set for 432 kW PV array mounting with 70 KG GI required for 1 KW array mounting	Rs 3326400/-
Electrical interconnection with grid @ Rs 3/watt	Array interconnection, connection to inverter and to LT panel/grid	Rs 1296000/-
Miscellaneous	Other BOS, Transportation, taxes etc	Rs 1178020/-
Total cost for 432 KW system		**Rs 24738420/-**
MNRE subsidy availed @ 30 % of project cost under institution scheme	Subsidy applicable for College institutions/universities	Rs 7421526/-
Net cost incurred by DTU	**Total cost for project minus subsidy availed**	**Rs 17316894/-**
Annual Units generated @ 5.27 Kwh/m2/day (for 300 working days)	**635677 KWh**	
Annual benefits @ Rs 9.50/ unit charged by Local Discom	Electricity charges high due to college lying under commercial consumer category	**Rs 6038932/-**
Payback period	**Rs 17316894/ Rs 6038932**	**2.87 years**

CONCLUSIONS

Thus roof top PV systems have a high potential in form of annual power generation and low payback periods under 3 years for the states like Delhi which are blessed with enormous sunshine availability throughout the year. Also current electricity prices are very high in Delhi for consumer which is not in residential category which also makes installing soar rooftop project financially viable in Delhi. Also land availability in Delhi in big problem which makes the rooftop concept a great idea to make Delhi power sufficient state. Also DTU will help in reducing Global warming by offsetting green house gas emissions (GHGs). Hence DTU administration will be highly benefitted by installing solar rooftop plant by making its contribution to complete 100 GW solar p0wer targets set by Government of India by 2022.

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