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COMPARATIVE STUDY OF PERFORMANCE OF GRID CONNECTED SOLAR PHOTOVOLTAIC POWER SYSTEM IN IIT ROORKEE CAMPUS

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ABSTRACT

The application of renewable energy in electrical power system is growing fast. Global environmental issues and the intensifying demand for energy, integrated with steady development in renewable energy technology, are opening up new opportunities for optimum utilization of renewable energy resources. Solar energy is the most clean, free inexhaustible resource among all the renewable energy resources available up to present. The Sun power absorbed by the earth which is about 1.8×10^{11} MW and the energy consumption on earth is a lot times more than the available rate. Solar power is used in form of Photovoltaic technology because photovoltaic technology has ability to generate power. Different types of light absorbing materials i.e. semiconductors are used. PV grid connected systems offer a wide range of both technological and commercial challenges, more so in India, which has just started a major initiative in this direction under the auspices of Jawaharlal Nehru National Solar Mission. This paper presents the comparative performance of Grid-connected solar photovoltaic (SPV) system in IIT Roorkee Campus in Uttarakhand state of India. The different technical parameters are used to carry out the performance analysis and comparative study.

Keywords: Comparative study, Mathematical Model, Performance Analysis, Solar Energy, Solar Photovoltaic, Solar Power Plant, Solar Radiation Data.

I. INTRODUCTION

The Renewable energy resources contribute about 30% as India's primary energy supply [1]. By conventional and renewable resources, India is advancing unceasingly in generating electricity. Using renewable energy, the grid capacity has been increased by nearly 4 times from past 14 years. The installed capacity based on renewable energy, was 3,497 MW (Mega Watt) in April 2002, which was nearly 3% of the total installed capacity used in India. In March 2016, the capacity has been increased to 38831.51 MW It has become 38831.51 MW on 31 March 2016, which was about 13% of the total installed capacity [1].

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In India, the installations of Solar Photovoltaic (SPV) system have increased after the unveiling of Jawaharlal Nehru National Solar Mission (JNNSM) by the Ministry of New and Renewable Energy, Government of India. The key goal of the JNNSM is to attain 20 GWp generations capacity via solar power systems by 2020 [2]. The energy from sun can be used either directly or indirectly in form of solar energy. It plays a significant role to diminish the harmful gases destructive for environment, generated during electricity production. According to International Energy Agency (IEA) report, SPV technology possibly will stop 100 Giga tons of CO_2emanations in the stretch of time of 2008- 2050 [3].

II. SOLAR PHOTOVOLTAIC SYSTEM

The process of translating photons (light) into voltage (electricity) is known as photovoltaic (PV) effect. Solar cells are used by solar photovoltaic system to capture sunrays and thus translate that energy directly into electricity. In any case, the specialized achievability and prudent operation of these systems at specific area relies on upon the variable solar resources. Beam, Diffuse and Total Solar Radiation are the three basic types of solar radiation.

Photovoltaic cells are usually made from silicon or other semi conductive materials and when sunrays are absorbed by these materials, the solar energy hits electrons slack from their atoms, letting the electrons to flow freely through the material to generate electricity. PV cells are long lasting. PV units are of three types: mono crystalline, polycrystalline, and thin-film in which mono crystalline works with greatest efficiency.

III. STUDY AREA

Accessibility of consistent solar radiation data is very important for the success of solar energy. India is situated where it receives 4-7 KWh of solar radiation per meter sq per day and that too with approx 250-300 sunny days per year [5].The study area is Roorkee which is located at latitude of 29.87°N and at 77.88°E longitude with an altitude of 268 m. Roorkee lies 172 km to the north of New Delhi, capital of India and is situated between the rivers Yamuna and Ganga, near to the foothills of Himalayas. Roorkee has an extreme and erratic continental climate as it is located far away from any major water bodies and has close propinquity to Himalayas. The total annual rainfall and annual mean daily solar radiation are 2600 mm and 5.22 kWh/m^2/day respectively. Indian Institute of Technology - Roorkee is one of the premier institutes of national importance in higher technological education in engineering, basic and applied research. Since its establishment, the Institute has played a very important role in providing the technical manpower and know-how to the country and in pursuit of research. Great quantities of unused rooftop area are there in IIT Roorkee. Nearly 25200 square meters rooftop area of different departments has been used for installing PV system in the campus [5]. Figure 1 shows the map of Uttarakhand and Figure 2 shows the map of IIT Roorkee where the SPV system installed.

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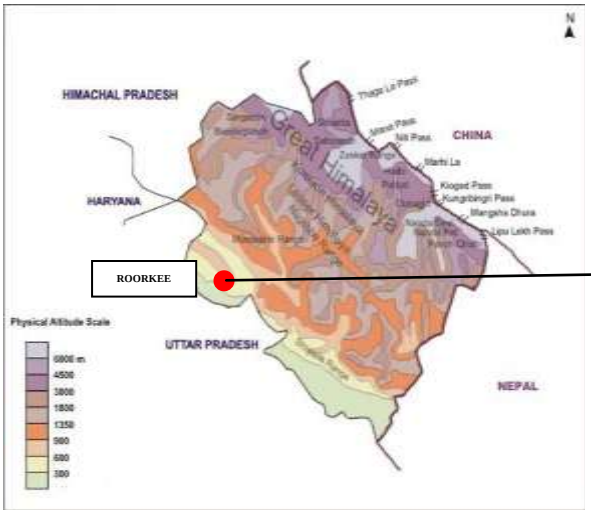

Fig.1 Map of Uttarakhand

Fig.2 Map of IIT Roorkee

IV. SPV SYSTEM PERFORMANCEMETHODOLOGY

The SPV plant performance is a function of equipment used, climatic conditions and system configuration. The solar PV system performances are evaluated using the following parameters according to the International Electro-technical Commission (IEC) standards 61724[6]:

4.1 Final yield (Y_F)

At the standard test conditions (1000W/m^2 irradiance, 25^0C ambient temperature and air mass 1.5g), Final Yield is termed as the ratio of total energy produced by PV system for a predefined period (E) to the rated output power ($P_{PV, Rated}$) of the installed PV System.

$$Y_F = E / P_{PV, Rated} \quad (1)$$

4.2 Reference yield (Y_R)

Reference yield is defined as the total in plane solar insolation (H_t) (kWh/m^2) divided by the reference irradiance (G) (1kW/m^2). Reference yield depicts equal number of hours at the reference irradiance.

$$Y_R = H_t / G \quad (2)$$

4.3 Performance Ratio (PR)

Performance ratio is termed as the ratio of final yield (Y_F) to reference yield (Y_R). It has no unit and is normalized performance parameter with respect to incident solar radiation. It represents the overall losses effect. This parameter is utilized to compute the long term changes in the performance. The increasing year wise PR values depicts increment in performance

$$PR = Y_F / Y_R \quad (3)$$

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4.4 Capacity factor (CF)

Capacity factor (CF) is defined as actual energy generate (E_{AC}**)** over a period of time divided by its potential output ($P_{PV,\ rated}$)for 24h per day for year.

$$CF= E_{AC}/(P_{PV,rated} * 8760) \quad (4)$$

4.5 System efficiency

The energy generated ($E_{AC,D}$) divided by the incident irradiance (H_t) at the module area (A_a) is termed as the system efficiency.

$$\eta_{sys,m} = E_{AC,D}/ (H_t * A_a) \quad (5)$$

Using these parameters, the world wide performances of the installed PV systems are evaluated.

V.MATHEMATICAL MODEL FOR PERFORMANCE OF SPV SYSTEM

It is a procedure to give the electrical energy output using the combination of basic parameters i.e. a monthly average efficiency and the photovoltaic module with local monthly mean temperature which multiplied by the monthly module solar insolation [7].

5.1 Electrical output of the PV module

The efficiency **(**η) of a solar photovoltaic module is a function of module solar radiation and cell temperature and is characterized by -

$$\eta= \eta_r[1- \beta (T_c- T_r) + \gamma \log_{10} I_{array}] \quad (6)$$

where, β depicts the temperature coefficient for cell efficiency and is almost constant for the operating temperature range come acrossin flat-plate module, η_r is the module efficiency measured at reference cell temperature for efficiency, T_r is the reference cell temperature at which η_r is computed, γ is a radiation-intensity coefficient for cell efficiency, and I_{array} is the radiation incident on the array per unit area, T_c is the cell temperature, Mostly the value of $\gamma = 0$, is taken in Eq. (6), that accept the accessible in the system[7].

The ambient temperature, T_a, is generally to add and subtract, from the two temperature terms T_c and T_r in parentheses in Eq. (6). After setting $\gamma = 0$, the efficiency is expressed as:

$$\eta= \eta_r[1- \beta (T_c- T_a) - \beta (T_a - T_r)] \quad (7)$$

The solar energy gain in the module to the electrical output and thermal losses as an energy balance:

$$\tau \alpha I_{array} = \eta I_{array} + U_L (T_c- T_a) \quad (8)$$

where, U_L is the thermal loss coefficient per unit area and $\tau\alpha$ is the transmittance-absorbance.

From Eq. (8) η is in the order of 0.1 $\tau\alpha$, it can be written as:

$$T_c- T_a = 0.9(\tau\alpha/ U_L) I_{array} \quad (9)$$

At nominal operating cell temperature (NOCT) conditions the $\tau\alpha/U_L$ can be determined from measurements of cell temperature, ambient temperature and solar radiation. (I_{array} =800 W/m^2, wind speed=1m/s, T_a =20^{0}C and η =0). From Eq. (8), replacing T_c by $T_{c,\,NOCT}$, T_a by $T_{a,\,NOCT}$, and η =0 then it is given as:

$$\tau\alpha/U_L = (T_{c,\,NOCT} - T_{a,\,NOCT}) / I_{array,\,NOCT} \quad (10)$$

Assuming over the whole operating temperature range $\tau\alpha/U_L$ to be constant, from Eq. (9) with $\tau\alpha/U_L$ given, from Eq. (10) can be used in Eq. (7) to obtain the module efficiency:

$$\eta = \eta_r[1 - 0.9\beta\,(I_{array} / I_{array,\,NOCT})\,(T_{c,\,NOCT} - T_{a,\,NOCT}) - \beta\,(T_a - T_r)] \quad (11)$$

Q_e the electrical energy output of the module is given by:

$$Q_e = \eta\, A\, I_{array} \quad (12)$$

where η is obtained from Eq. (11) and A is the module area.

5.2 System Parameters

Table 1: System parameters for mathematical model

(1)	Reference Efficiency, η_r	0.138
(2)	Temperature Coefficient, β	0.004/^{0}C
(3)	Solar radiation annually, I_{array}	217.5 W/m^2 or 1905.3 kWh/m^2
(4)	Solar radiation at NOCT condition, $I_{array,\,NOCT}$	800 W/m^2 or 7008 kWh/m^2
(5)	Cell Temperature at NOCT condition, $T_{c,\,NOCT}$	27.7^{0}C
(6)	Ambient Temperature at NOCT condition, $T_{a,\,NOCT}$	20^{0}C
(7)	Ambient Temperature, T_a (Average Annually)	20^{0}C
(8)	Reference cell temperature, T_r	25^{0}C

VI. MATHEMATICAL MODELFORINVERTER

The main inverters electrical characteristics for grid connection are DC to AC conversion efficiency, MPPT efficiency, harmonic distortion and power factor [8]. By testing various technologies, the mathematical models were developed. Finally, 3% losses consider by the inverter in final SPV model generation.

VII. DATA COLLECTION

Data collection from different sources was done in order evaluate solar radiation.

7.1 Insolation Data

Table 2 shows the average insolation data collected at Roorkee. The actual power output depends upon the insolation at the place at STC of 1000 W/m^2 insolation [9].The average insolation value is 5.22kWh/m^2/day for evaluating the power output of modules.

Table 2: **Insolation data for Roorkee**

Month	**Insolation (kWh/m^2/day)**
April	6.83
May	7.37
June	6.47
July	5.63
August	5.38
September	5.29
October	5.13
November	3.83
December	3.21
January	3.16
February	4.43
March	5.86
Yearly average	5.22

7.2 Solar Devices

Solar PV system consist of different devices connected together to produce the required amount of energy. For making these devices interconnected with each other, they should have some common and standard parameters.

(i) Modules

Modules in PV system are used which have high efficiencies so that they can achieve the required power outputs. The modules from Tata Power solar system Ltd. manufacturer have been used with favorite ranges to accomplish this work. Electrical rating under STC (1000W/m^2, A.M. 1.5, Cell temperature= 25^{O}C) [10].

Table 3: **Module Parameters**

Manufacturer	Tata Power Solar system Ltd.
Technology	Poly crystalline Silicon
Model	TS230MBT
Pm (W)	230
Vm (V)	29.1
Im (A)	7.9
V_{OC} (V)	36.7
I_{SC} (A)	8.4
Cell Efficiency (%)	15.75
Module Efficiency (%)	13.80

(ii) Inverters

IIT Roorkee is connected to grid having 3 phase system. Therefore, Inverter of three phases with the following parameters from Delta 30, 20, 15 and 11 kW series are recommended [10].

Table 4: Technical Specification of the Inverter

Details	30TL	20TL	15TL	11TL
Inverter type	MPPT	MPPT	MPPT	MPPT
MPPT Voltage range	480-800 V DC	350-800 V DC	350-800 V DC	350-800 V DC
Input DC Power (nominal)	31kW	20.4kW	15.3kW	11.6kW
Max. AC output voltage-nominal	415V, 3Ph & 50Hz	415V, 3Ph & 50Hz	415V, 3Ph & 50Hz	415V, 3Ph & 50Hz
Nominal apparent AC power	30 kVA	20 kVA	15 kVA	11 kVA
Operating temperature range	–20 °C to +60 °C	–20 °C to +60 °C	–20 °C to +60 °C	–20 °C to +60 °C
Inverter Dimension	952 x 625 x 275 mm	952 x 625 x 275 mm	952 x 625 x 275 mm	685 x 410 x 185 mm

7.3 Plant details

Table 5: Number of Modules, Peak Power Output and Module Area

S.No.	Site Location	No. of PV Modules	Module Area(m^2)	Peak Power Output(kWp)
1	IIT Roorkee Campus	7910	13186	1816

VIII. CALCULATION AND ANALYSIS

For IIT Roorkee campus, following are the Performance indices of installed solar PV system:

(i) Final Yield, $Y_F = E / P_{PV, Rated} = 1213.1$(h/d)

(ii) Reference yield, $Y_R = H_t/G = 1905.3$ (h/d)

(iii) Performance Ratio, $PR = Y_F / Y_R = 0.6368$

(iv) Capacity Factor, $CF = E_{AC,a} / (P_{PV,rated} * 8760) = 0.1385$

(v) System efficiency, $\eta_{sys,m} = E_{AC} / (H_t * A_a) = 0.0877$

Table 6: Monthly Performance Ratio, Capacity Factor and Efficiency

S.No.	Month	Generation (kWh)	Performance Ratio (%)	Capacity Factor (%)	Efficiency (%)
1	April 2014	220669	59.30	16.88	08.17
2	May 2014	234812	56.59	17.40	07.80
3	June 2014	218887	62.10	16.74	08.55
4	July 2014	161005	50.81	11.92	07.00
5	August 2014	195747	64.62	14.49	08.90
6	September 2014	196299	68.11	15.01	09.38
7	October 2014	194718	67.44	14.41	09.29
8	November 2014	180896	86.69	13.84	11.94
9	December 2014	125960	69.71	09.32	09.60
10	January 2015	96753	54.37	07.16	07.49
11	February 2015	160315	71.19	13.14	09.80
12	March 2015	216846	65.72	16.05	09.05
13	**Total**	**2202907**	**63.68**	**13.85**	**08.77**

Using Eq. (11) and system parameters given in the Table 1, the efficiency was found to be: Efficiency (η) =13.97%.

Given, Area of module = 13186 $m^2$and Solar radiation annually, I_{array} = 1905.3 (kWh/m^2)

Now, using Eq. (12) Q_e the electrical energy output of the module is given by: $Q_e = \eta A I_{array}$ = 3509723 Units.

Table 7: Generation by Mathematical Model, Inverter and Actual

S.No.	Period (2014-2015)	Solar Radiation Data (kWh/m^2)	SPV Model Generation (kWh)	Inverter Generation (kWh)	Actual Generation (kWh)
1	April 2014	204.9	377443	366119.7	220669
2	May 2014	228.5	420916	408288.5	234812
3	June 2014	194.1	357548	346821.6	218887
4	July 2014	174.5	321443	311799.7	161005
5	August 2014	166.8	307260	298042.2	195747
6	September 2014	158.7	292339	283568.8	196299
7	October 2014	159.0	292891	284104.3	194718
8	November 2014	114.9	211655	205305.4	180896
9	December 2014	099.5	183287	177788.4	125960
10	January 2015	098.0	180524	175108.3	96753
11	February 2015	124.0	228418	221565.5	160315
12	March 2015	181.7	334707	324665.8	216846
13	**Total**	**1905.3**	**3509723**	**3404431**	**2202907**

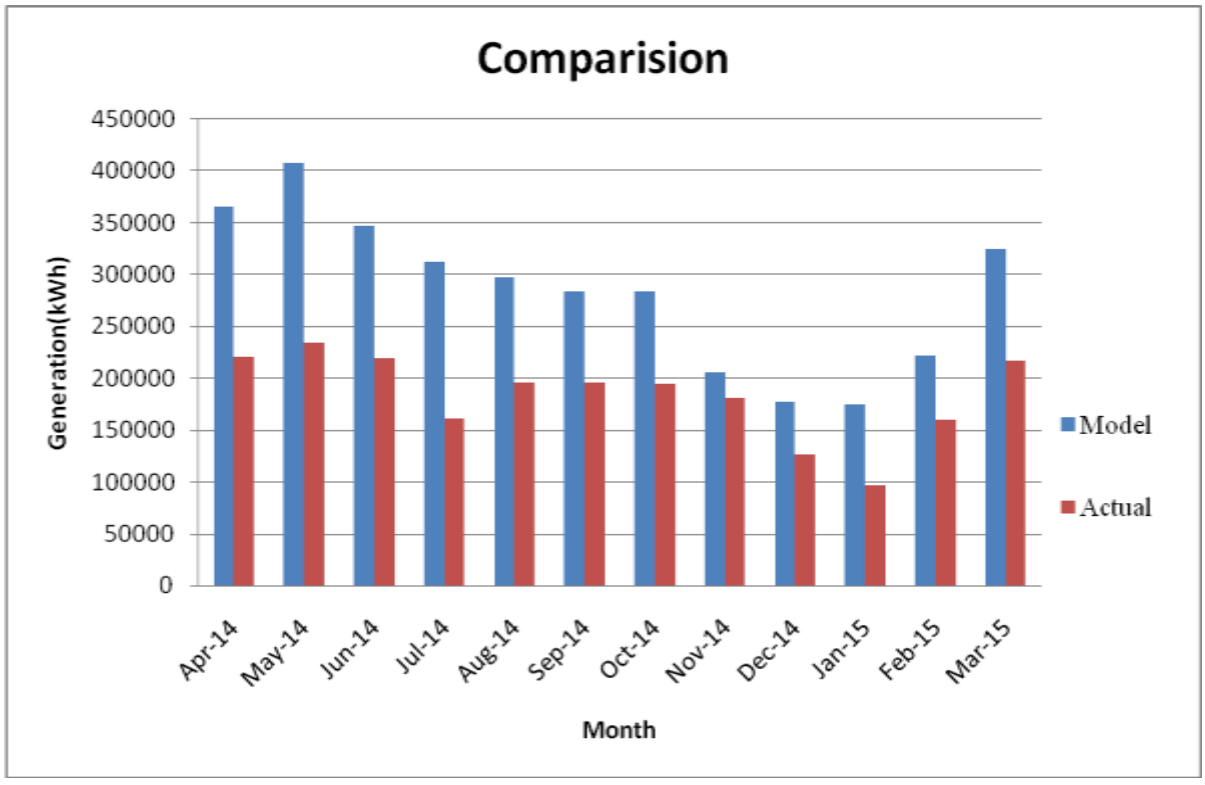

Fig. 3: Comparative status of Mathematical Model and Actual

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IX. TECHNO ECONOMICAL ANALYSIS

The cost study depends upon the following given factors:

(i) System Cost = Rs. 14.14 crore

(ii) O&M cost (1^{st} five Yrs) = Rs. 13.75 lacs

(iii) O&M cost (6-25 Yrs) =Rs. 3.49 to 15.55 lacs per year

Unit generation cost = Rs. 8.5 per unit (without subsidy)

= Rs. 0.85 per unit (with subsidy)

Electricity Generation= 22.02 lacs units annual

Now, getting subsidy as IIT Roorkee is a central government institute. So, the unit generation cost can be used as Rs. 0.85 per unit.

Table 8: Payback Period of the Plant

Capital Cost of the system (Rs.)	14.14 crore
Subsidy (Rs.)	12.72 crore
Actual Capital Cost (Rs.)	1.41 crore
Saving per annum (Rs.)	18.72 lacs
Payback Period (Year)	7.5 years

X. ECO-FRIENDLY SYSTEM

The main Objective of the Renewable Energy System (Solar, Wind, Hydro etc.) is to reduce the harmful gases like CO_2 from the environment and to generate the power as well as make the system eco-friendly. The Annual Energy Consumption from 2010 to 2013 of IIT Roorkee Campus is about73.6 M units. Now, to generate the required amount of energy using Non-renewable resource i.e. Diesel is used about 44,000 Liters by which 105 tones CO_2 emitted. Assuming 35% state supply from thermal sources, the CO_2 emitted is 5,768 tones (assumption 0.82 kg/kWh) [11]. Now, the Solar PV system installed in IIT Roorkee campus is reducing about 2464 tons of CO_2 per annum from the environment.

XI. RESULT AND DISCUSSION

A study is conducted for solar PV energy generation through mathematical model and actual from IIT Roorkee. At the same atmospheric condition, the generation by mathematical model then inverter is 3404431 kWh and generation by PV system in IIT Roorkee is 2202907 kWh during a year (April 2014 to March 2015). This study is based upon the system efficiency and the efficiency of mathematical model, inverter and actual module was found to be 13.97%, 97% and 8.76% respectively. Due to the some factors like PV technology, solar radiations, ambient

temperature and tilt angle that affect the performance of solar PV system, and the generation is about 1201524 kWh less in IIT Roorkee.

XII. CONCLUSIONS

Comparative study of Performance of Grid connected Solar PV system in IIT Roorkee Campus leads to following conclusion: The solar radiation data from National Renewable Energy Laboratory (NREL) and National Aeronautics and Space Administration (NASA) are collected. The data of solar radiation and energy production were analyzed and performance indices was represented as Performance ratio, Capacity Factor and efficiency and values of these factors were found to be as 63.58%, 13.83%and8.76%respectively.A comparative study of Solar Photovoltaic System in IIT Roorkee campus through mathematical model and actual is show that 1201524 kWh less generation due to the losses in the PV system in IIT Roorkee.It has been found that the solar PV systems are working effectively and performance of the system has been found satisfactory. Based on the Techno-economic analysis carried out the Payback period of the PV systems is found to be as 7.5 Years. The solar PV system is Eco-friendly and good for Environment due to 2464 ton per annumCO_2 Reduction in IIT Roorkee Campus.

REFERENCES

[1] Ministry of Power, Government of India, Central Electricity Authority, http://www.cea.nic.in/Reports/monthly Reports/executive summary/March-2016.pdf.

[2] Jawaharlal Nehru National Solar Mission. Guidelines for selection of new grid connected solar power projects www.mnre.gov.in; July 2010.

[3] Zhang X, Zhao X, Smith S, Xu J and Yu X, ―Review of R&D progress and practical application of the solar photovoltaic/thermal (PV/T) technologies, Renewable & Sustainable Energy Reviews, 16(1), (2012), 599–617.

[4] Saini R.P, Solar photovoltaic Design and Application, Notes, AHEC IIT Roorkee, 2014.

[5] Solarification of IIT Roorkee Campus, AHEC IIT Roorkee 2010.

[6] Sharma V, Chandel SS. Performance analysis of a 190kWp grid interactive solar photovoltaic power plant in India. Energy2013; 55:476–85.

[7] Siegel MD, Klein SA, Beckman WA. A simplified method for estimating the monthly average performance of photovoltaic systems. Solar Energy 1981; 26:413.

[8]GirbauZ,ChenloF,CaamañoMartinE.ComparacióndedossistemasFVSdistintosconectadosaredeenlamismalocalidad. In:12thCongressoIbéricoy7th CongressoIberoamericanodeEnergiaSolar,Vigo,Spain;2004,p.1031–6.

[9] Synergy Enviro Engineers, source NREL.

[10] http://www.tatapowersolution.com.

[11] Kumar Arun, Green/Sustainable agenda for educational Institutions: Case study from IIT Roorkee India, 8th UN-CECAR International Conference on UNIVERSITY LED DEVELOPMENT Kuala Lumpur, 30th May 2014.