Performance And Simulation Analysis Of 80KW Grid Connected Rooftop Solar Power Plant At St.Peter's Engineering College, Hyderabad using PV Watts India

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***Abstract*—** In grid connected rooftop solar PV system, available rooftop area on buildings is used for setting up solar power plant and DC power generated from solar photovoltaic (SPV) cells is converted to AC power by solar grid inverter and is fed to the grid during day time. In night when solar power is not sufficient, loads are served by drawing power from grid. In this paper, real time and Simulation analysis of 80KW solar photovoltaic roof top grid connected power plant at St.Peter's Engineering College, Hyderabad city is carried out using PV Watts India simulation software. The real time meter readings of import side and export side of energy and energy output of inverters are recorded. The simulation results of DC energy output of PV module and AC energy output of inverter are presented. The annual average solar radiation at St.Peter's Engineering College is 6.93 kWh/m^2/day. The system losses and capacity factor are calculated using PV Watts India software. The DC energy output of PV array is 153189.7 KWh/annum and AC energy output of inverter is 1, 47,018KWh.

***Keywords*— Capacity factor; Peak demand; Energy; solar radiation; System losses; solar panel.**

I. INTRODUCTION

St.Peter's Engineering College, Hyderabad is located at latitude of 17.35 ^{0}N and longitude of 78.45 ^{0}E and at an elevation of 505m from sea level. [6].

Electric utilities are finding it difficult to meet rise in peak demand and as a result, most of cities and towns are facing severe electricity shortages [5]. It is proposed to achieve a minimum of 3000MW's of grid connected rooftop solar power plants in Telangana state by 2018.

II. ON - GRID SOLAR ROOF TOP POWER PLANTS

Solar Photovoltaic cells convert sunlight energy to DC current through a photovoltaic process. The solar PV systems may be: off-grid and on-grid. Batteries are needed in off-grid plants [1]. Batteries require replacement once in every 3-5 years in off-grid. In Grid connected solar rooftop power plant, the DC power generated from solar photovoltaic (SPV) panel is converted to AC power using solar grid inverter and is fed to the grid either of 11KV lines or of 400/230V, three / single phase lines and if any shortfall of solar energy is imported from grid[2]. A schematic diagram of a grid connected solar rooftop photovoltaic power plant is shown in Fig.1.

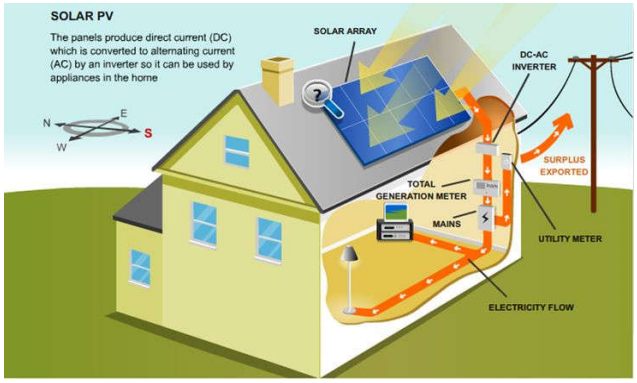

Fig1. A Schematic diagram of a Grid connected Solar Roof Top Photo Voltaic Power Plant.

III. SOLAR PANEL CHARACTERSTICS

The typical I-V curve and P-V curve for a solar panel are shown in fig.2 [3

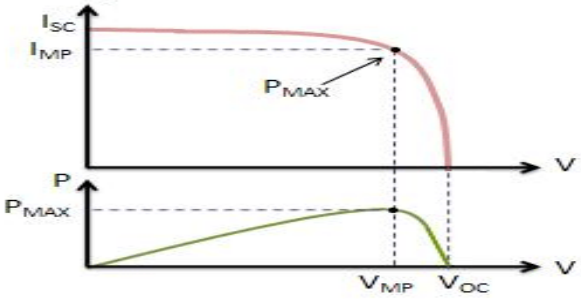

Fig.2. P-V and I-V curve of a solar cell at a particular temperature & irradiation

In the above figure, the Knee point is called "maximum power point" (MPP) [4]. In the curve, I_{SC} is the solar panel circuit current in short circuit condition & V_{OC} is the solar panel circuit voltage under open circuit condition. I_{MP} and V_{MP} are those of tracking point for maximum current and maximum voltage respectively and can be track by MPPT system. Thus, the multiplication of both I_{MP} and V_{MP} gives the condition of maximum power for solar module as

$P_{MAX} = V_{MP} * I_{MP}$ watt

IV COMPONENTS OF SOLAR PV SYSTEM

A Grid-connected solar PV system consists of following main components [8]:

A. Solar photovoltaic (PV) modules

Solar Photovoltaic modules are mounted on the roof of any buildings and convert sunlight energy into direct current. Photovoltaic modules are formed with an array to get required voltage and current.

B. Solar PV array support structure

Solar PV array support structure consists of galvanized steel structures secure the solar PV modules on the roof of any buildings.

C. Solar grid inverter

The solar panels feed a special inverter know as Solar grid inverter which converts the DC voltage coming from the solar panels directly into AC power to match the grid.

D. Balance of system

Other components of solar rooftop power plant are cables, junction boxes, fuses etc. The expected life of solar PV plant is 25 years.

V PERFORMANCE ANALYSIS OF PV SYSTEM

The performance parameters are developed by International Energy Agency [10] for analyzing the performance of solar PV grid interconnected system.

A. System parameters [9]

1. *Array yield*

It is equal to the time from which the Photovoltaic plant has to operate with nominal solar generator power P_o to generate array DC energy E_A. Its units are kW h/*d** KWp.

$$Y_A = E_A/P_O$$

Where, Array energy output per day $E_A = I_{dc*}V_{dc*}t$ (KW h),

I_{dc} = DC current (A)
V_{dc} = DC voltage (V)
P_0 = Nominal Power at STC.

2. *Reference yield*

The reference yield is the total in-plane irradiance *H* divided by the Photovoltaic's reference irradiance *G*. It represents the under ideal conditions obtainable energy. If *G* equals 1 kW/m², then Yr is the number of peak sun hours or the solar radiation in units of kW h/m². Its units are h/d.

Y_R = [kW h/m²]/1 kW/m².

$Y_R = H_t/G_o$

Where,

H_t = Total Horizontal irradiance on array plane (Wh/m²), G_o = Global irradiance at STC (W/m²).

3. *Final yield*

It is the annual, monthly or daily net AC energy output of the system divided by the peak power of the installed Photovoltaic array at standard test conditions of 1000 W/m² solar irradiance and 25 °C cell temperature. Its units are kW h /*d** kW p.

$Y_F = E_{PV, AC} / P_{maxG, STC}$

4. *Performance ratio*

The performance ratio is the final yield divided by the reference yield. Performance ratio can be defined as comparison of plant output compared to the output of the plant could have achieved by taking into account irradiation, panel temperature, availability of grid, size of the aperture area, nominal power output, temperature correction values.
PR = Y_F/Y_R.

5. *Capacity utilization factor*

It is defined as real output of the plant compared to theoretical maximum output of the plant.

CUF = Energy measured (kW h)

/ (365 ∗ 24 ∗ installed capacity of the plant).

6. *Inverter efficiency*

The inverter efficiency appropriately called as conversion efficiency is given by the ratio of AC power generated by the inverter to the DC power generated by the PV array system. The instantaneous inverter efficiency is given by,

$\eta inv = P_{AC} / P_{DC}$

7. *System efficiency*

The instantaneous daily system efficiency is given as PV module efficiency multiplied by inverter efficiency.
$\eta sys,T = \eta PV,T * \eta inv,T$

8. *Energy output or energy fed to utility grid*

The energy generated by the PV system is the measure of energy across the inverter output terminals for every minute [7]. It is defined as the total daily monitored value of AC power output and the monthly AC energy generated.

B. *Specific plant losses*

Energy losses occur in various components in a grid connected SPV Power plant under real operating conditions. These losses are evaluated using the monitored data.

1. *Array capture losses* (L_C): These are of two types.

2. *Thermal capture loss* (L_{CT}): Losses caused by cell temperature higher than 25 °C are called thermal losses. Thermal capture loss (L_{CT}) is the difference between reference field and corrected reference field.

3. *Miscellaneous capture loss* (L_{CM}): Losses that are caused by wiring, string diodes, low irradiance, partial shadowing, mismatching, maximum power tracking errors, limitation through dust, losses generated by energy conduction in the photovoltaic modules

$L_{CT} = Y_R - Y_{CR}$
$L_{CM} = Y_{CR} - Y_A$
$L_C = Y_R - Y_A$

4. *System losses* (L_S):

These losses are caused by inverter, conduction and losses of passive circuit elements.

$L_S = Y_A - Y_F$

VI REAL TIME SYSTEM DESIGN

The main target is to design and install 80KW solar rooftop solar power plant.

A. Key facts of solar rooftop power plant

Plant capacity in KWp : 80KWp Rooftop Solar power plant
PV Technology/Module: Polycrystalline modules
Power conditioning unit: 80 KVA (30+30+20)
Power evacuation : 400/230V, three/single-phase, 50HZ

A typical Design of 80KW Solar Roof Top Power Plant of St.Peter's Engineering, Hyderabad city is shown in Fig 3.

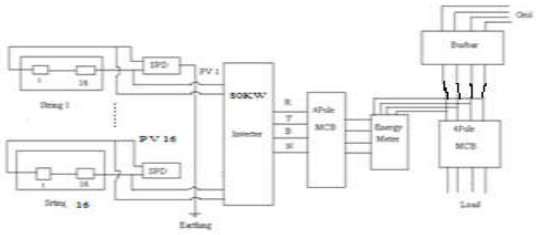

Fig.3 A typical Design of 80KW Roof top solar power plant at St.Peter's Engineering College, Hyderabad. Actual on-site 80KW Solar Roof Top Power Plant of St.Peter's Engineering, Hyderabad city is shown in Fig 4.

Fig .4 Actual onsite of 80KW solar roof top plant at St.Peter's Engineering College, Hyderabad City

B. System capacity based on rooftop area

Total Power output = Total area x Solar irradiance x
Conversion efficiency
80000 = Total area x 1000 Watts/m² x 0.1641

Total area required for 8KWp = 487 Sq.m = 5245 sq.feet
The rooftop area required to install 80KWp is around 5250 sq.feet.

C. Number of PV panels for the system

Divide the total watt-hours per day needed from PV panels by the rated output watt-peak of PV modules.

Capacity of each module: 315Wp

Number of PV panels or modules required =

80000Wp / 315WP = 254

Number of strings as per system Design = 16 Numbers

Number of solar panels in each string = 16

The maximum power of this module is 315Wp; hence it requires nearly 256 modules to design 80KW PV system. The selected PV is manufactured by Vikram Solar and onsite arrangement of solar PV modules at St.Peter's Engineering College, Hyderabad City is shown in Fig 5.

Fig.5 Actual onsite of 80KW solar roof top PV modules at St.Peter's Engineering College, Hyderabad City

The PV module parameters and ratings [5] are given in Table 1 and more specifications of PV module and dimension [13] are given in Table 2.

Table1. PV module parameters and ratings

Electrical Characteristics	
Rated Maximum power (Pmax)	315Wp
Maximum power voltage (Vmp)	38.33 V
Maximum power current (Imp)	8.22A
Open circuit voltage (Voc)	46.04V
Short circuit current (Isc)	8.85A
Module efficiency	16.41%
Operating temperature	45°C

Table 2. PV module specifications and dimension

Specifications and Dimensions of PV module	
Solar cells	Poly crystalline solar cells
Solar cell size	156 mmx156 mm(6 inx6 in)
Number of cells(pieces)	72 (6x12)
Module dimensions	1956 mm x992 mm x40 mm
Weight	27 kg
Front glass	4 mm tempered glass
Frame	Anodized aluminum alloy
Protection degree	IP 65
High efficiency	16.41%
Grid connection	ON/OFF grid

D. Solar Grid Inverter rating

The solar array PV capacity is 80KW. The solar grid inverter requires will be in range of 76KW to 88KW. In solar grid connected plant, input rating of inverter should be same as PV array rating [12]. For this system, solar grid inverter used is 80KVA (30KVA+30KVA+20KVA) of Shenzhen Growatt New Energy Technology Co.Ltd. make is shown in Fig 6.

Fig.6 Actual onsite 80KVA solar grid inverter at St.Peter's Engineering College, Hyderabad City

The inverter parameters are given in Table 3

Table 3. Inverter parameters

Inverter specifications for 30KWp Inverter	
Model Name	Growatt 30000TL3-SE
Maximum DC voltage	1000 d.c. V
Maximum input current	2*34 d.c. A
Maximum apparent power	33000VA
Nominal output current	3*34 a.c. A
Nominal output voltage	230V/400 a.c. V
Inverter specifications for 20KWp Inverter	
Model Name	Growatt 20000UE
Maximum DC voltage	1000 d.c. V
Maximum input current	26/26 d.c. A
Maximum apparent power	20800VA
Nominal output current	32 a.c. A
Nominal output voltage	230V/400 a.c. V

E. Distribution Transformer rating

The details of distribution transformer used in this
Analysis is summarized as follows:

.

Location of Distributing Transformer: St.peter's Engineering College, Hyderabad city

Capacity of Distribution Transformer: 250KVA

The rating of SRTPV capacity = 80KWp

Total generating capacity in KWp = 80KWp

F. Feeder rating

The details of feeder are summarized as follows:

Name of 11KV Feeder: St.Peter's Engineering College, Hyderabad city.

Feeder Number: CF

Name of 66 / 11 KV substation: Kompally, Hyderabad city

Type of conductor / cable (Size): Rabbit

G. Meter specifications

The meter specifications are given below:

Meter Make: Secure meters Ltd.

Model No: Premier 300 Type E3M024, 3-phase, 4-wire

Meter Number (RR Number): RRN1458

Tariff: LT – 2

Sanctioned Load: 100 KW

VII REAL TIME TEST RESULTS

A. Meter output readings on Import and Export side

The meter readings of energy meters on 03.03.2018 are given in Table 4.

Table 4 Meter reading on Import and Export side on 03.03.2018

Date & Time	**Import side**				**Export side**			
03-03-2018	KWh	KVAh	KVArh	KVA	KWh	KVAh	KVArh	KVA
9:00am	3474.6	3574.5	412.6	17.94	2243.4	2367.7	115.5	14.60
10:00am	3479.6	3579.6	413.4	17.9	2243.4	2367.7	115.5	14.60
11:00am	3483.2	3583.3	414.0	17.9	2243.4	2367.7	115.5	14.60
12:00pm	3489.2	3589.5	415.6	17.9	2243.4	2367.7	115.5	14.60
1:00pm	3499.2	3599.8	418.0	17.9	2243.4	2367.7	115.5	14.60
2:00pm	3507.3	3608.1	419.8	17.9	2243.4	2367.7	115.5	14.60
3:00pm	3515.7	3616.6	420.7	17.9	2243.4	2367.7	115.5	14.60
4:00pm	3526.8	3627.8	421.8	17.9	2243.4	2367.7	115.5	14.60
5:00pm	3534.1	3635.0	422.2	17.9	2243.4	2367.7	115.5	14.60

The import and export meter readings of energy meters on 03.03.2018 are given in in Fig. 7

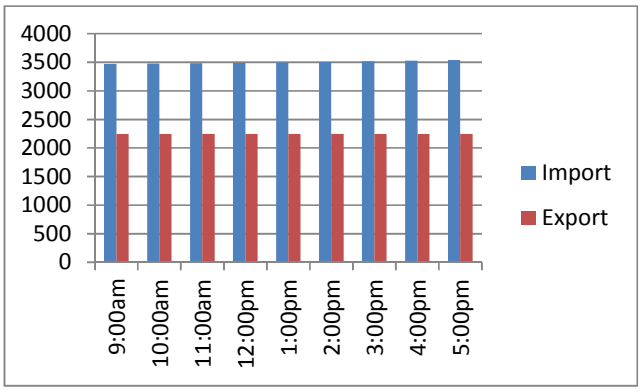

Fig.7 The import and export meter readings of energy meters in KWh on 03.03.2018

The energy at the import side on 03/03/18 at 9:00AM is 3479.6KWh & export side is 2243.4KWh so the energy injected into grid is 2243.4 KWh.

The energy at the import side on 03/03/18 at 1:00PM is 3499.2KWh & export side is 2243.4KWh so the energy injected into grid is 2243.4 KWh.

The Energy output of three inverters from the actual site of 80KW solar roof top plant at St.Peter's Engineering College, Hyderabad on 03.03.2018 as shown in Table. 5

Table5. Energy output of Inverters on 03.03.2018

Date & Time 03-03-2018	Energy output of 30 KVA Inverter in KWh	Energy output of 30 KVA Inverter in KWh	Energy output of 20 KVA Inverter in KWh	Total Energy output of 80 KVA Inverter in KWh
9:00am	13	12	9	35
10:00am	21	20	13	54
11:00am	40	39	26	105
12:00pm	52	52	34	138
1:00pm	87	87	57	231
2:00pm	93	93	61	247
3:00pm	113	112	74	299
4:00pm	118	118	78	314

The energy output of First 30KVA inverter at 9:00AM on 03.03.2018 is 13KWh, second 30KVA inverter is 12KWh and 20KVA inverter is 9KWh. The total output energy from 80KW PV Plant on 03.03.2018 at 9:00 am is 35KWh.

The energy output of First 30KVA inverter at 1:00PM on 03.03.2018 is 87 KWh, second 30KVA inverter is 87 KWh and 20KVA inverter is 57 KWh. The total output energy from 80KW PV Plant on 03.03.2018 at 1:00 pm is 231KWh.

The energy output of three inverters on 03.03.2018 are given in Fig. 8

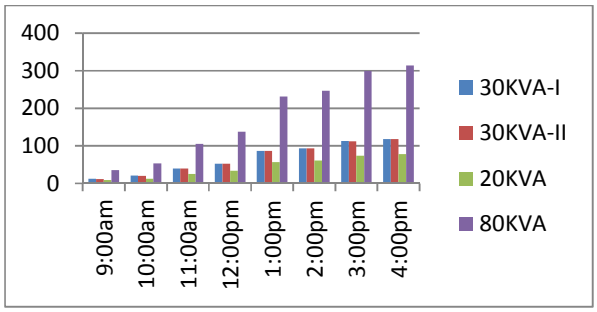

Fig.8 The energy output of three inverters on 03.03.2018

VIII SIMULATION ANALYSIS RESULTS USING PV Watts India

PV Watts India software [11] is one of the simulation software developed by NREL to estimate the performance of the solar power plant.

A. Resource Data and System info

The resource data and system info for inputs considered for 80KW roof top solar power plant are shown in Fig.9

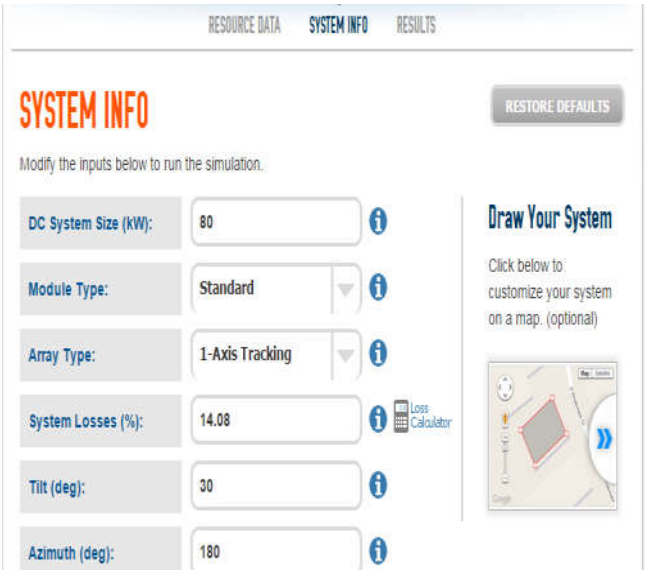

Fig.9 Resource data and system info of 80KW solar rooftop plant

The system considered is DC system size 80KW, module type is standard, and array type is 1-axis tracking with tilt angle 30^0 and Azimuth angle 180^0. The system losses are calculated as 14.08%.

B. Results of 80KW rooftop solar plant

The maximum energy is generated in the month of January is 14,435 KWh and minimum energy generated in the month of July is 8800 KWh. The total amount of energy generated from 80KW plant for the entire year is 1, 47,018KWh is shown in Fig. 10.

RESOURCE DATA SYSTEM INFO RESULTS

RESULTS 147,016 kWh/Year*

Print Results

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (□)
January	7.99	14,435	52,401
February	8.59	13,836	50,223
March	8.26	14,277	51,825
April	7.83	12,871	46,722
May	7.23	12,562	45,598
June	5.31	9,454	34,317
July	4.66	8,800	31,942
August	5.06	9,562	34,709
September	6.20	11,189	40,616
October	7.06	12,803	46,474
November	7.70	13,412	48,686
December	7.62	13,817	50,155
Annual	6.96	147,018	□ 533,668

Fig.10 Simulation results

The location and PV system specifications are given in Fig.11

Location and Station Identification	
Requested Location	Hyderabad,INDIA
Weather Data Source	(IN) Gridded 10km Satellite Data 2.9 km
Latitude	17.35° N
Longitude	78.45° E
PV System Specifications *(Commercial)*	
DC System Size	80 kW
Module Type	Standard
Array Type	1-Axis Tracking
Array Tilt	30°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1
Ground Coverage Ratio	0.4
Economics	
Average Cost of Electricity Purchased from Utility	3.63 □/kWh
Performance Metrics	
Capacity Factor	21.0%

Fig 11. The location and PV system specifications Loss diagram

The Simulated results of DC array output and Inverter output of 80KW rooftop solar plant are shown in Table 6.

Table 6. Simulated results of DC array output and Inverter output of 80KW rooftop solar PV plant

Month	Solar radiation KWh/m²/day	AC output of Inverter(KWh)	DC Output of PV array(KWh)
Jan	7.994908	14435.45	15019.09
Feb	8.585751	13835.59	14391.09
March	8.258698	14276.74	14858.06
April	7.831453	12871.13	13406.92
May	7.226706	12561.51	13083.18
June	5.312614	9453.836	9879.511
July	4.656275	8799.533	9209.479
Aug	5.061445	9561.674	9991.998
Sep	6.203059	11188.88	11667.41
Oct	7.057816	12802.88	13342.35
Nov	7.696882	13412.25	13963.35
Dec	7.616053	13816.86	14377.28
Annaul	6.96	147016.3	153189.7

The solar radiation is 6.96 kWh/m²/day. The solar energy incident on the solar panels will convert into electrical energy. The capacity factor PV array is 21% and system losses are 14.08%. After the inverter losses the available energy obtained at the inverter output is 1, 47,017KWh /year and the DC output of array is 153189.7Kwh as observed from Table 6.

IX. CONCLUSIONS

The real time design of an 80KW solar PV power plant located on the roof of a St. Peter's Engineering College building in Hyderabad city is carried out by means of determining the engineering standards and realistic constraints of design. The required shaded free roof top area for installing such plant is found to 5250 sft. We study how to establish a real time design of 80KW photovoltaic solar roof top power plant and installation of the 80KW roof top plant and the meter readings are recorded.

A performance and Simulation analysis of 80 KW peak grid connected solar photovoltaic power plant installed at Hyderabad was evaluated on annual basis using PV Watts India PV Simulation software. The following conclusions are drawn from the study.

- From the simulation results, Maximum total energy generation of 14,435 KWh was observed in the month of Jan and lowest total energy generation of 8800 KWh was observed in the month of July.
- From the simulation results, the annual average solar irradiation is 6.96 kWh/m²/day. Total annual average DC energy output of the PV array is 153189.7 KWh and the output of the inverter is 1, 47,017KWh.
- From the simulation results, the system losses are 14.08% and the capacity factor is 21%.
- The energy at the import side on 03/03/18 at 9:00AM is 3479.6KWh & export side is 2243.4KWh so the energy injected into grid is 2243.4 KWh.
- The energy at the import side on 03/03/18 at 1:00PM is 3499.2KWh & export side is 2243.4KWh so the energy injected into grid is 2243.4 KWh

- The energy output of First 30KVA inverter at 9:00AM on 03.03.2018 is 13KWh, second 30KVA inverter is 12KWh and 20KVA inverter is 9KWh. The total output energy from 80KW PV Plant on 03.03.2018 at 9:00 am is 35KWh.

- The energy output of First 30KVA inverter at 1:00PM on 03.03.2018 is 87 KWh, second 30KVA inverter is 87 KWh and 20KVA inverter is 57 KWh. The total output energy from 80KW PV Plant on 03.03.2018 at 1:00 pm is 231KWh

- The real time measured energy output of 80KW solar grid connected roof top power plant is 401.6KWh/day and the simulation output of 80KW solar grid connected roof top power plant using PV Watts India software is 402.8 KWh/day and 1,47,018 Kwh/year.

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