Online Monitoring And Simulation Of 30KW Grid Connected Rooftop Solar Power Plant At St.Peter's International School, Hyderabad using PV Syst

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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 monitoring and Simulation analysis of 30KW solar photovoltaic roof top grid connected power plant at St.Peter's International School, Hyderabad city is carried out using PV Syst simulation software. The real time meter readings on import side and export side of energy and energy output of inverter are recorded. The simulation results of energy output of PV array, energy output of inverter and energy injected into grid are presented. The annual average solar radiation at St.Peter's International School is 5.87 kWh/m^2/day. The performance ratio and PV losses due to irradiance level are calculated using PVSyst software.

Keyword: - *Capacity factor, Energy demand, AC Power, solar radiation, System losses.*

1. INTRODUCTION

St.Peter's International School, Hyderabad is located at latitude of 17.45 ^{0}N and longitude of 78.45 ^{0}E and at an elevation of 518 m 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

2. 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 [3].

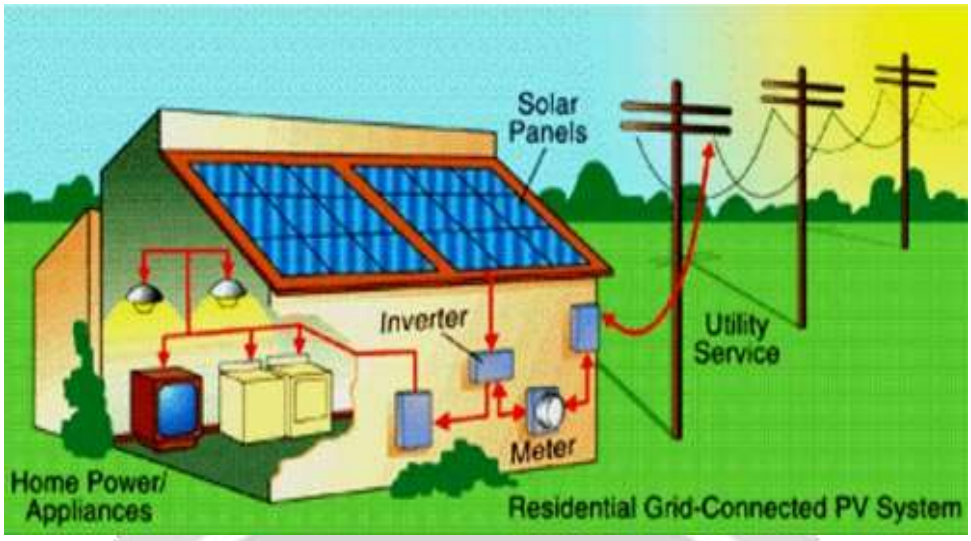


Fig1. A Schematic diagram of a Grid connected Solar Roof Top Photo Voltaic Power Plant**.**

3. SOLAR PANEL CHARACTERSTICS

The typical I-V curve and P-V curve for a solar panel are shown in fig.2 [11].

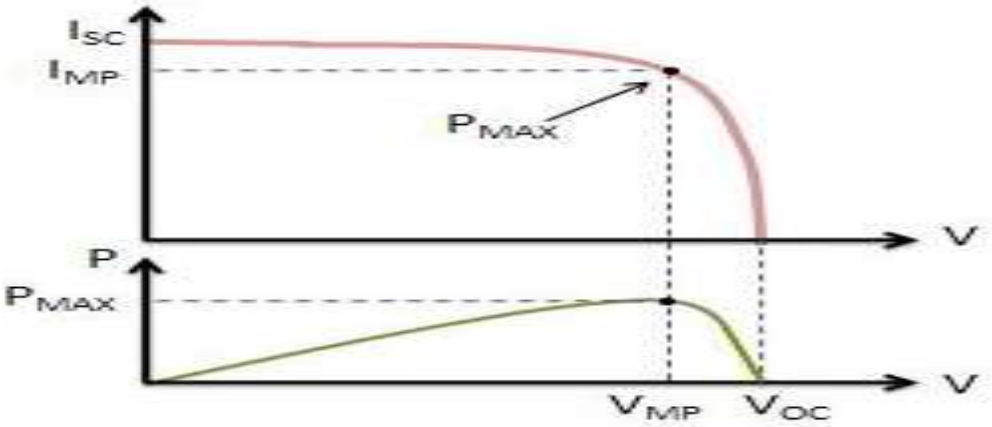


Fig.2. P-V and I-V curve of a solar cell at a particular temperature & irradiation

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

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

4. 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. The size of a solar PV system depends on the 90% energy consumption of the building and the shade-free rooftop area available. 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

Solar grid inverter tied PV systems consist of solar panels and a grid-tie inverter, with no batteries. 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.

5. 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/m^2, then Yr is the number of peak sun hours or the solar radiation in units of kW h/m^2. Its units are h/d.

Y_R = [kW h/m^2]/1 kW/m^2.

$Y_R = H_t/G_o$

Where,H_t = Total Horizontal irradiance on array plane (Wh/m^2), G_o = Global irradiance at STC (W/m^2).

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/m^2 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,

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

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.

a. ***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.

b. ***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

$L_{CT} = Y_R - Y_{CR}$

$L_{CM} = Y_{CR} - Y_A$

$L_C = Y_R - Y_A$

2. ***System losses* (L_S):**

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

$L_S = Y_A - Y_F$

6. REAL TIME SYSTEM DESIGN

The main target is to design and install 30KW solar rooftop solar power plant.

A. Key facts of solar rooftop power plant

Plant capacity in KWp : 30KWp Rooftop Solar power plant

PV Technology/Module: Polycrystalline modules

Power conditioning unit: 30 KVA

Power evacuation : 400/230V, three/single-phase, 50HZ

Actual on-site 30KW Solar Roof Top Power Plant of St.Peter's International School, Hyderabad city is shown in Fig 3.

Fig .3 Actual onsite of 30KW solar roof top plant at St.Peter's International School, Hyderabad City

B. System capacity based on rooftop area

Total Power output = Total area x Solar irradiance x Conversion efficiency

30000 = Total area x 1000 Watts/m^2 x 0.1641

Total area required for 30KWp = 182 Sq.m = 1958 sq.feet

The rooftop area required to install 30KWp is around 1960 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 =

30000Wp / 315WP = 96

Number of strings as per system Design = 06 Numbers

Number of solar panels in each string = 16

The maximum power of this module is 315Wp; hence it requires nearly 96 modules to design 30KW PV system. The selected PV is manufactured by Vikram Solar and onsite arrangement of solar PV modules at St.Peter's International School, Hyderabad City is shown in Fig 4.

Fig.4 Actual onsite of 30KW solar roof top PV modules at St.Peter's International School, 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 30KW. 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 30KVA of Shenzhen Growatt New Energy Technology Co.Ltd. Make is shown in Fig 5.

Fig.5 Actual onsite 30KVA solar grid inverter at St. International School, 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

E. Distribution Transformer rating

The details of distribution transformer used in this

Analysis is summarized as follows:

.Location of Distributing Transformer: St.peter's International School, Hyderabad city

Capacity of Distribution Transformer: 63KVA

The rating of SRTPV capacity = 30KWp

Total generating capacity in KWp = 30KWp

F. Feeder rating

The details of feeder are summarized as follows:

Name of 11KV Feeder: St.Peter's International School, 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

Tariff: LT – 2

Sanctioned Load: 100 KW

7. REAL TIME TEST RESULTS

A. Meter output readings on Import and Export side

The energy at the import side of meter on 18/05/2017 is 19.4KWh & export side is 8.7KWh so the energy injected into grid is 8.7 KWh after utilizing for School load. The meter readings of energy meters on 12/03/2018 are given in Table 4.

Table 4 Meter reading on Import and Export side on 12/3/2018

Date 12/03/18	**Import**		**Export**		**NET KWH**
	KWH	KVAH	KWH	KVAH	
9:00AM	113569.9	113671.5	4020	9923.5	109549.9
11:00AM	113602.8	113677.3	4048.7	9927.2	109554.1
4:25PM	113613.7	113688.8	4055.7	9959.7	109558.0
4:33PM	113615.2	113690.1	4055.9	9959.7	109559.3

The energy at the import side on 12/03/18 at 11:00AM is 113602.8 KWh & export side is 4048.7KWh so the energy injected into grid is 4048.7 KWh after utilizing for School load of 109554.1KWh.

The energy at the import side on 12/03/18 at 04:25PM is 113613.7 KWh & export side is 4055.7 KWh so the energy injected into grid is 4055.7 KWh after utilizing for School load of 109558KWh. The meter readings of energy meters on 13/03/2018 are given in Table 5.

Table 5 Meter reading on Import and Export side on 13/3/2018

Date 13/03/18	**Import**		**Export**		**NET KWH**
	KWH	KVAH	KWH	KVAH	
9:00AM	114023.4	114098.2	4056.0	9959.7	109967.4
10:00AM	114025.4	114100.2	4056.3	9961.3	109969.1
11:00AM	114026.7	114101.7	4057.5	9966.0	109969.2
12:00PM	114027.6	114102.5	4060.7	9971.4	109966.9
1:00PM	114030.2	114105.3	4062.3	9976.2	109967.9
2:00PM	114037.4	114112.5	4062.3	9976.2	109975.2
3:00PM	114040.1	114115.1	4062.8	9980.2	109977.3

The energy at the import side on 13/03/18 at 11:00AM is 114026.7 KWh & export side is 4057.5 KWh so the energy injected into grid is 4057.5 KWh after utilizing for School load of 109969.2KWh.

The energy at the import side on 13/03/18 at 02:00PM is 114037.4 KWh & export side is 4062.3 KWh so the energy injected into grid is 4062.3 KWh after utilizing for School load of 109975.2KWh.

The Energy output of 30KVA inverter on 09/03/2018 from the actual site of 30KW solar roof top plant at St.Peter's International school, Hyderabad as shown in Table. 6 and in Fig.6

Table 6. Energy output of 30KVA Inverter on 09/03/2018

Date & Time 09/03/18	Energy output of 30 KVA Inverter in KWh
9:00AM	25
10:00AM	31
11:00AM	44
12:00PM	64
1:00PM	85
2:00PM	104
3:00PM	119
4:00PM	131
5:00PM	136

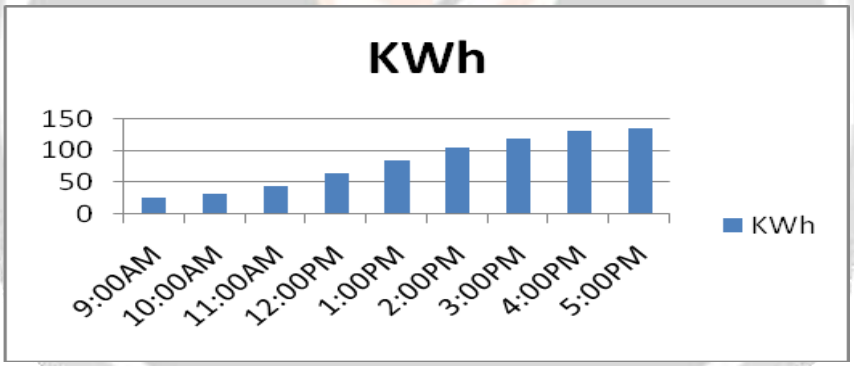


Fig.6 Energy output of 30KVA Inverter on 09/03/2018

The energy output of 30KVA inverter on 09/03/2018 at 9:00AM is 25KWh, 10:00AM is 31KWh, 11:00AM is 44KWh,12:00PM is 64KWh,1:00PM is 85KWh, 2:00PM is 104KWh,3:00PM is 119KWh, 4PM is 131KWh and at 5:00PM is 136Kwh So average energy output of 30KW plant is 120 to 130KWh/day,4030 KWh /month and 48360 KWh/ year.

The Energy output of 30KVA inverter on 10/03/2018 from the actual site of 30KW solar roof top plant at St.Peter's International school, Hyderabad as shown in Table. 7 and in Fig.7

Table 7. Energy output of 30KVA Inverter on 10/03/2018

Date & Time 10/03/18	Energy output of 30 KVA Inverter in KWh

9:00AM	24
10:00AM	28
11:00AM	38
12:00PM	59
1:00PM	78
2:00PM	96
3:00PM	103
4:00PM	107
5:00PM	110

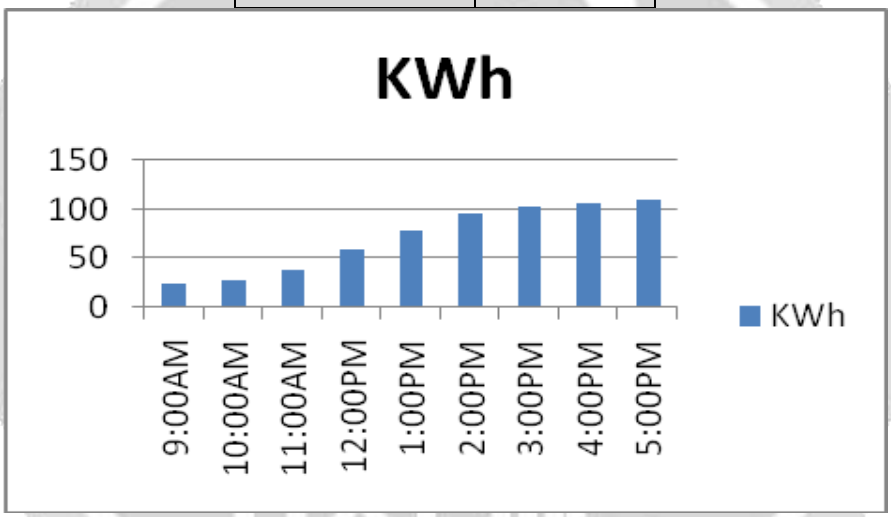


Fig.7 Energy output of 30KVA Inverter on 10/03/2018

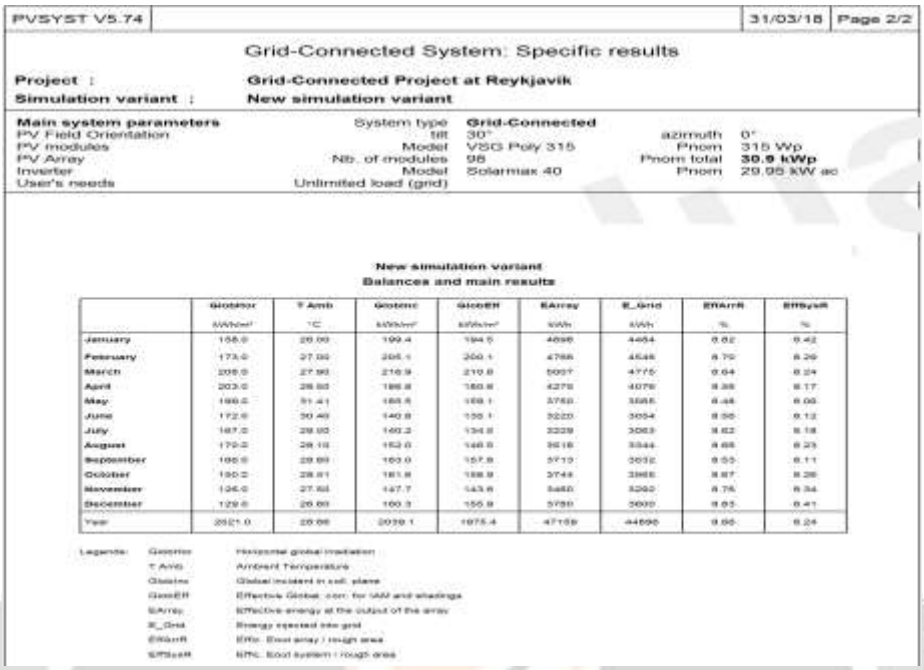
8. SIMULATION ANALYSIS RESULTS USING PV Syst

PV syst software is one of the simulation software developed to estimate the performance of the solar power plant. This software is capable of evaluating the performance of grid-connected, stand-alone and pumping systems based on the specified module selection. The program accurately predicts the system yields computed using detailed hourly simulation data

A. Balances and main results

The maximum energy is generated in the month of March (5007KWh) and minimum energy is in the month of June (3220 KWh). The total amount of energy that is injected in to the grid for the entire year is 44896KWh is shown in Table.8.

Table.8 Simulation results


PVSYST V5.74 | 31/03/18 | Page 2/2

Grid-Connected System: Specific results

Project : Grid-Connected Project at Reykjavik
Simulation variant : New simulation variant

Main system parameters				
PV Field Orientation	System type	**Grid-Connected**		
PV modules	tilt	30°	azimuth	0°
PV Array	Model	VSG Poly 315	Pnom	315 Wp
Inverter	Nb. of modules	96	Pnom total	**30.9 kWp**
User's needs	Model	Solarmax 40	Pnom	29.95 kW ac
	Unlimited load (grid)			

New simulation variant
Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	158.0	26.00	199.4	194.5	4698	4454	8.82	8.42
February	173.0	27.00	205.1	200.1	4786	4548	8.79	8.36
March	205.0	27.90	216.9	210.8	5007	4775	8.64	8.24
April	203.0	28.80	186.8	180.8	4278	4079	8.38	8.17
May	166.0	31.41	165.5	159.1	3763	3585	8.48	8.08
June	172.0	30.40	140.8	135.1	3220	3054	8.56	8.12
July	167.0	29.60	140.2	134.8	3229	3063	8.62	8.18
August	170.0	29.10	152.0	146.5	3618	3344	8.68	8.23
September	166.0	28.60	163.0	157.9	3710	3532	8.53	8.11
October	160.0	28.01	181.8	188.9	3744	3565	8.87	8.26
November	136.0	27.50	147.7	143.6	3460	3292	8.76	8.34
December	129.0	26.00	160.3	155.9	3750	3600	8.93	8.41
Year	2021.0	28.06	2039.1	1975.4	47159	44696	8.66	8.24

Legends: GlobHor Horizontal global irradiation
T Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
EffArrR Eff. Eout array / rough area
EffSysR Eff. Eout system / rough area

The energy at inverter output per day is given in Fig.8

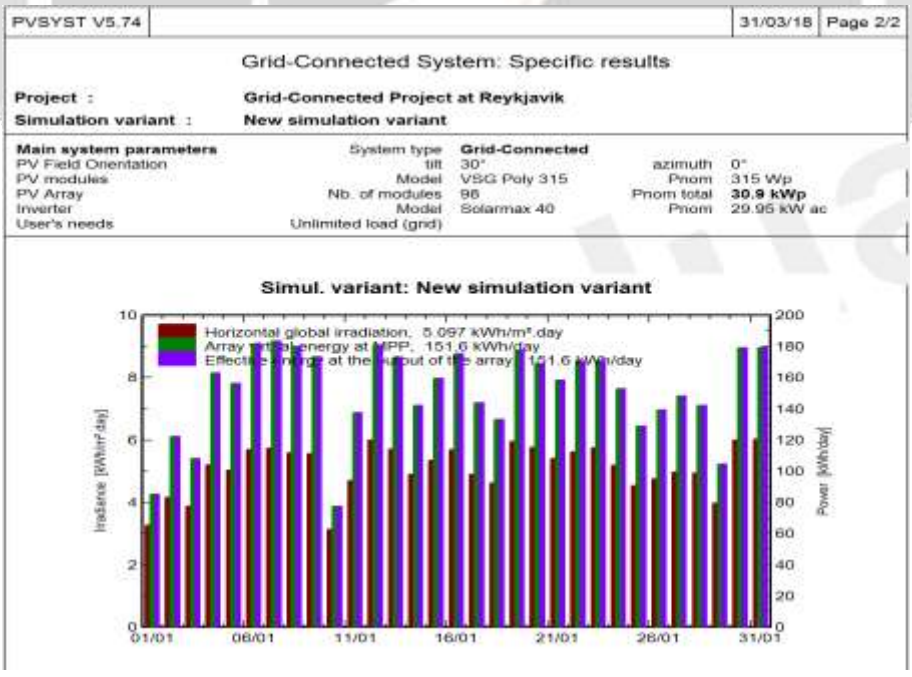


Fig 8. The energy at inverter output per day

The horizontal global irradiation is 5.097 KWh/m^2.day. The effective energy at the output of array is 151.6KWh/day.

B. Loss diagram and the Energy output of array

The global horizontal irradiance is 2021 kWh/m^2. The effective irradiation on the collector plane is 1975 kWh/m^2. Therefore, the loss in energy is 3.1%. The solar energy incident on the solar panels will convert into electrical energy. After the PV conversion, the nominal array energy at is 61411KWh. The efficiency of the PV array is 11.63% at standard test condition (STC). Array virtual energy at MPP obtained is 47161KWh and the effective energy at the output of array is 47159KWh. The PV losses due to irradiance level is 2501KWh.The available energy obtained at the inverter output and Energy injected to grid is 44896 KWh as shown in Fig.9 and Fig. 10

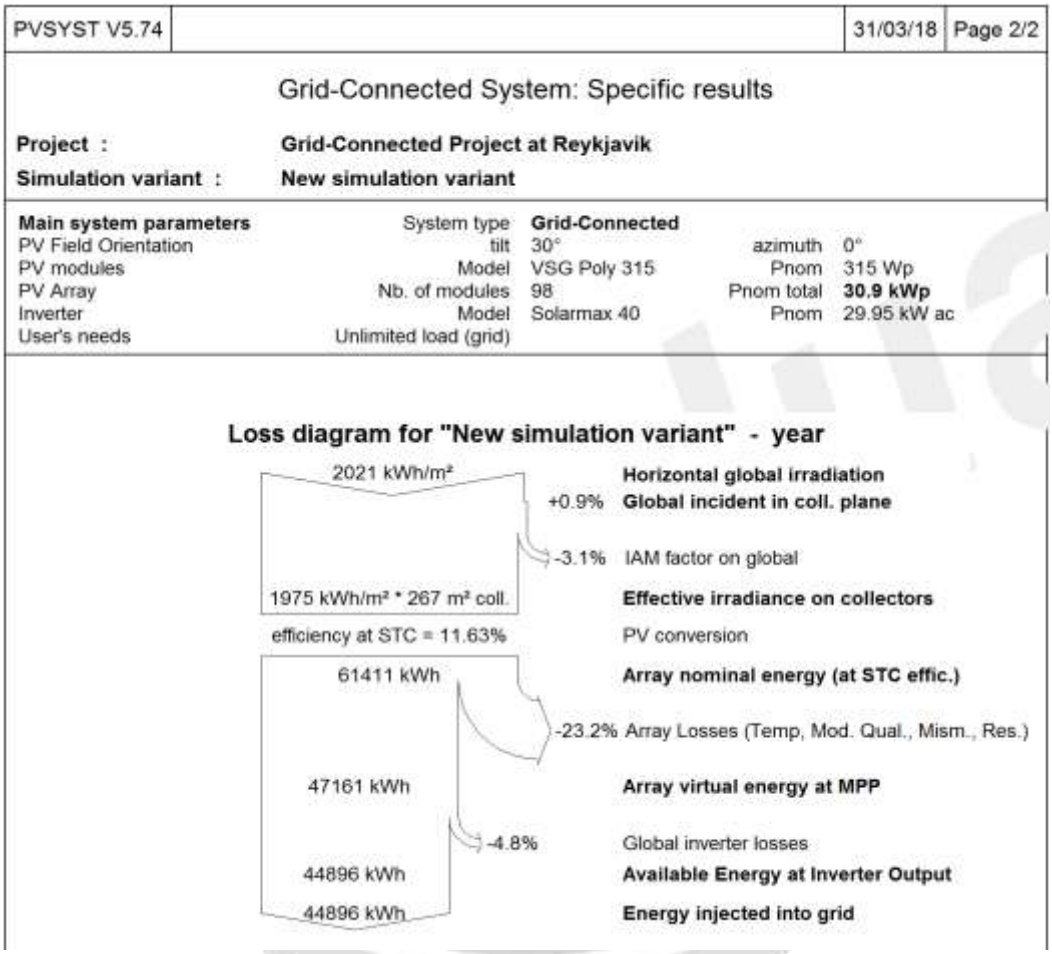


Fig.9 Energy supplied to the user

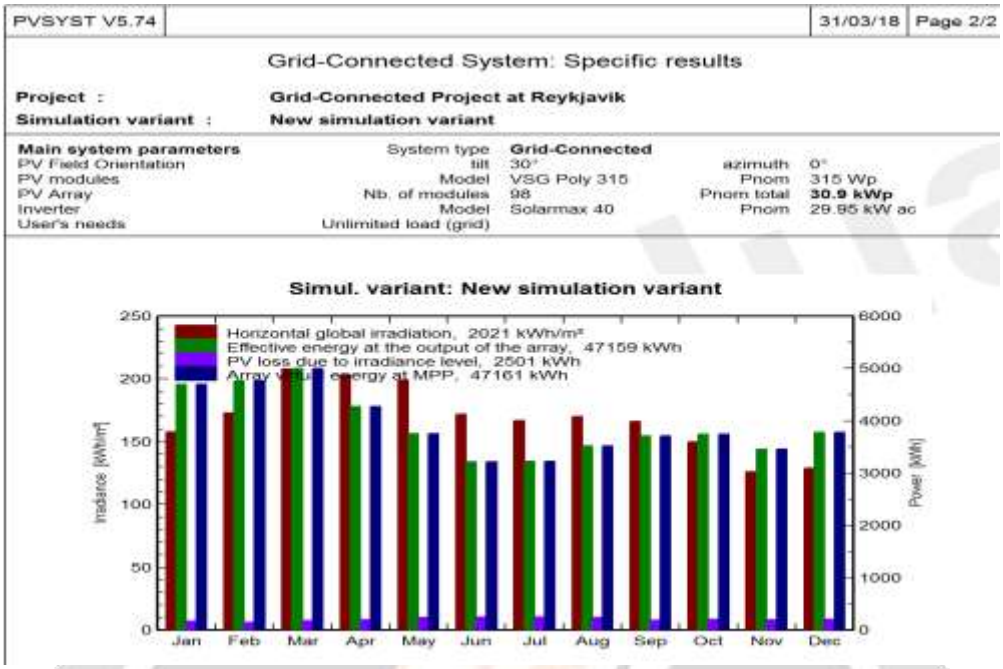


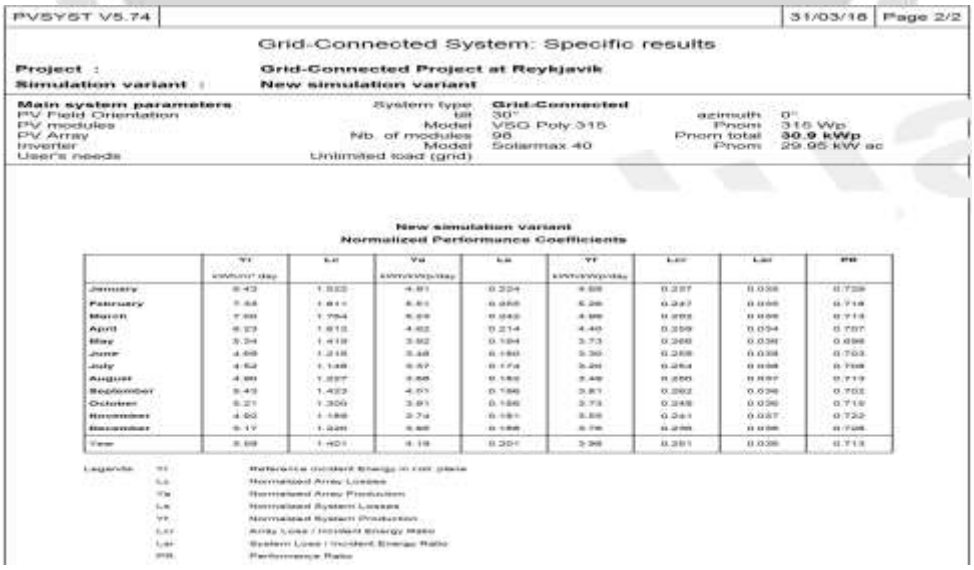
Fig. 10 Effective energy at the output of array

C. Performance ratio

The annual average performance ratio is 71.3% The PV syst results performance ratio is not much difference with the actual performance ratio of the solar plant observed using SCADA system in real time.

The normalized performance coefficients are shown in Table.9

Table.9 Normalized performance coefficients



9. CONCLUSIONS

The real time design of a 30KW solar PV power plant located on the roof of a St. Peter's International School 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 1960 sft. We study how to establish a real time design of 30KW photovoltaic solar roof top power plant and installation of the 30KW roof top plant and the meter readings are recorded.

A performance and Simulation analysis of 30 KW peak grid connected solar photovoltaic power plant installed at St. Peter's International School, Hyderabad was evaluated on annual basis using PV Syst. The following conclusions are drawn from the study.

- From the simulation, the maximum energy is generated in the month of March is 5007KWh and minimum energy is in the month of June is 3220 KWh. The total amount of energy that is injected in to the grid for the entire year is 44896KWh
- Annual global horizontal irradiation is 2021 kWh/m^2. Global incident energy that is incident on the collector plane annually is 1975 KWh/m^2. Total energy obtained from the output of the PV array is 47159KWh; the energy injected into the grid is 44896KWh.
- The annual average array final yield is 3.98KWh/KWp/day at reference yield of 5.59KWh/m^2.day
- The 30 KW solar power plant is operating with good amount of Performance ratio of 71.3%.
- The energy at the import side on 12/03/18 at 11:00AM is 113602.8 KWh & export side is 4048.7KWh so the energy injected into grid is 4048.7 KWh after utilizing for School load of 109554.1KWh
- The energy at the import side on 13/03/18 at 11:00AM is 114026.7 KWh & export side is 4057.5 KWh so the energy injected into grid is 4057.5 KWh after utilizing for School load of 109969.2KWh.
- The real time measured energy output of 30KW solar grid connected roof top power plant is 120-130KWh/day and the simulation output of 30KW solar grid connected roof top power plant using PV syst software is 151.6 KWh/day.

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