LNT-SPV-06

In a multi-specialty hospital located at Vellore (Tamil Nadu), with various loads under operation as shown in the table. And 5% of daily energy requirements need to be catered from Solar PV System. For this building, design a grid-connected Solar PV System. The building has got sufficient area to install the panels.

S.No	Area	Load (kW)	Duration(hrs)
1	Medical Equipment	1000	6
2	Lighting	600	12
3	HVAC Loads	2000	12
4	Elevator, Escalator	200	6
5	Other Equipment	400	5

[Assume 15% losses in Solar PV System and 20% safety margin for Inverter]

For the same, design an off-grid system with an autonomy of 2 days.
[Assume 15% losses in battery with 80% deep discharge factor].

Note: Any missing data can be assumed with relevance.

Task-1:

Selected PV module of **400Wp JA Solar JAM72-S10-400-PR make.**

Build a suitable MATLAB/Simulink block diagram and examine its characteristics under:

i) Constant Temperature and Variable Irradiance
ii) Constant Irradiance and Variable Temperature

Task-2:

Compute the manual calculations for the given demand in on-grid system and estimate

i) number of PV modules
ii) Peak Sun Hours
iii) Inverter Sizing (Central Inverter)
iv) Number panels in series
v) Number of strings

Compute the manual calculations for the given demand in off-grid system and estimate

i) number of PV modules
ii) Inverter Sizing (Central Inverter)
iii) Battery Capacity
iv) Number panels in series
v) Number of Strings
vi) Number of batteries in series and parallel

Considering PV module of **400Wp JA Solar JAM72-S10-400-PR** make, Central Inverter of **Ingeteam Sun Power 500 M275 Indoor** make, charge controller of 48V and battery 12V, 200Ah.

Task-3:

Design an on-grid PV system using SAM Software for the given power demand choosing PV Module **400Wp JA Solar JAM72-S10-400-PR** and Central Inverter of **Ingeteam Sun Power 500 M275 Indoor**.

Obtain a detailed report with

- **i)** Number of PV Modules
- **ii)** Inverter Selection
- **iii)** Number of Strings
- **iv)** Annual Energy Yield

Task-4:

Design an on-grid PV system using PVSyst Software for the given power demand choosing PV Module **400Wp JA Solar JAM72-S10-400-PR** and Central Inverter of **Ingeteam Sun Power 500 M275 Indoor**.

Obtain a detailed report with

- **i)** Number of PV Modules
- **ii)** Inverter Selection
- **iii)** Number of Strings
- **iv)** Annual Energy Yield
- **v)** Area Required
- **vi)** Also examine with near shading analysis with scene construction (consider Few Trees, Transmission line tower etc.,)

Task-5:

Design a PV system with a Boost Converter using MATLAB/Simulink and examine its performance. For the PV make **400Wp JA Solar JAM72-S10-400-PR**, choose the number of parallel strings and number of series connected modules as calculated in Task-2 (on-grid system). Design a boost converter with a duty ratio of 50% for the PV system and hence determine the following for constant and varying irradiation. [Assume a switching frequency of 25kHz and load resistance of 10 ohm]

- **i)** PV Voltage
- **ii)** PV Current
- **iii)** PV Power
- **iv)** Load Voltage
- **v)** Load Current
- **vi)** Output Power

LNT-SPV-06-Task 1

Solar PV Module Make:

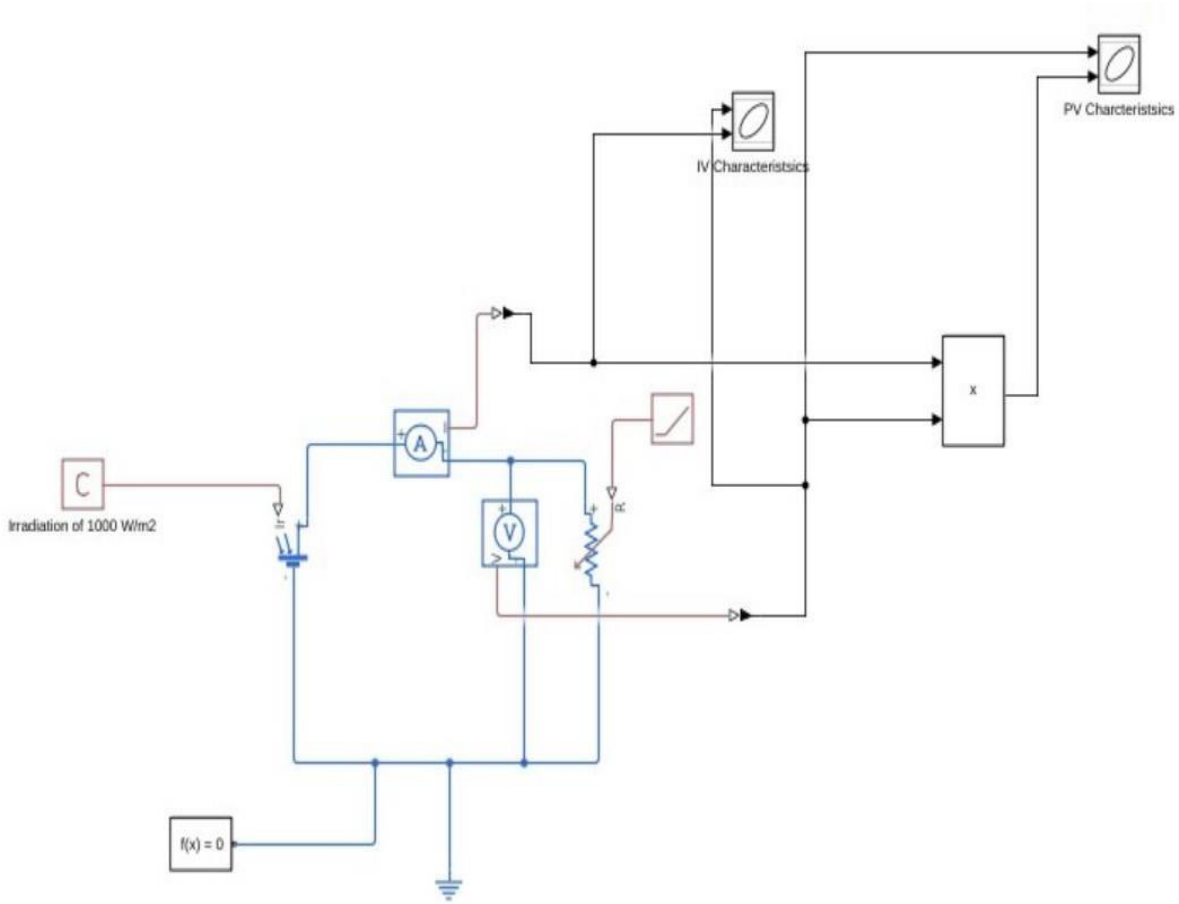
400Wp JA Solar JAM72-S10-400-PR make.

Solar PV Array Configuration:

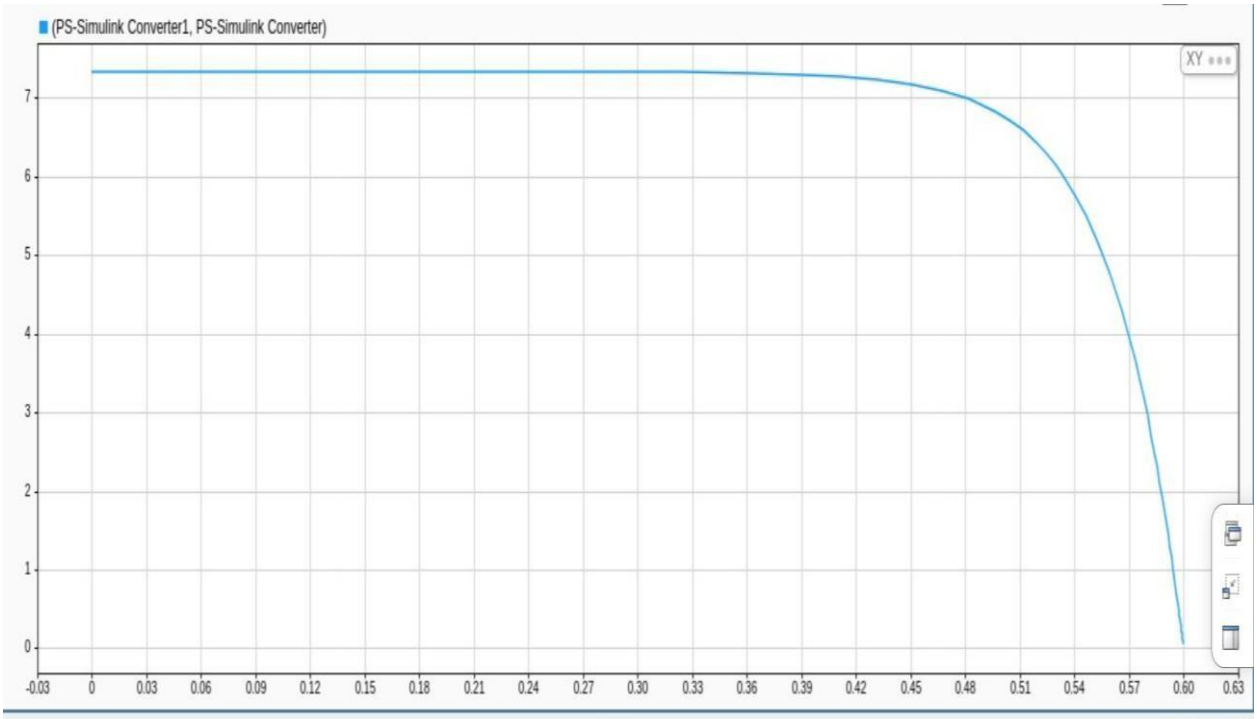
1 Parallel string with 1 Series connected modules per string.

Load Resistance, R = 10 ohm

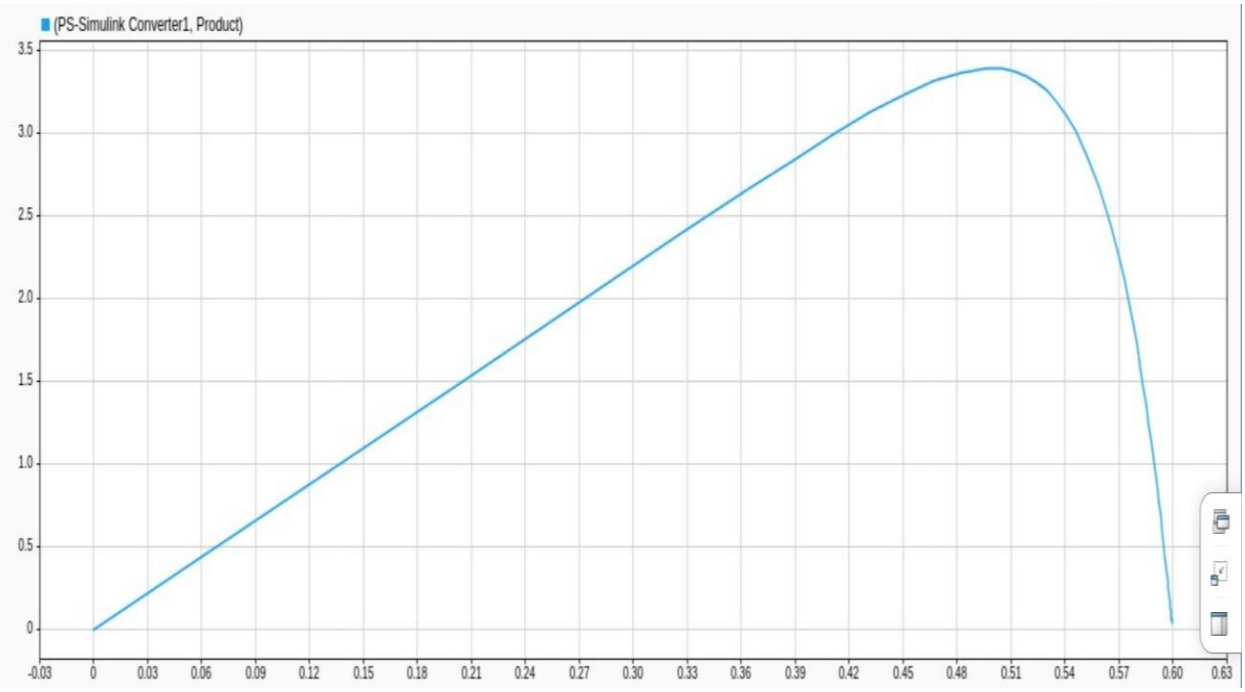
a) MATLAB Model for a single PV Cell Simulation



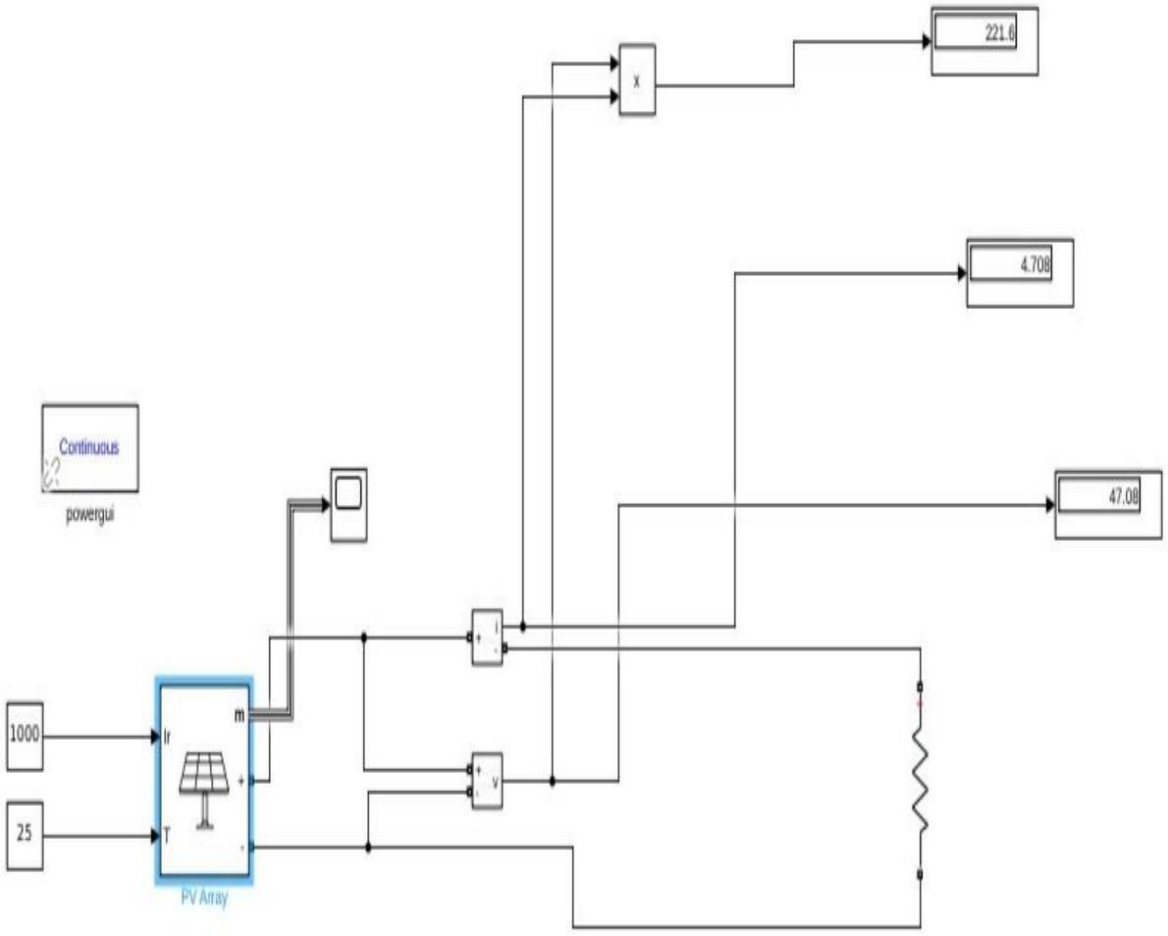
Current Versus Voltage (IV) Characteristics



Power Versus Voltage (PV) Characteristics

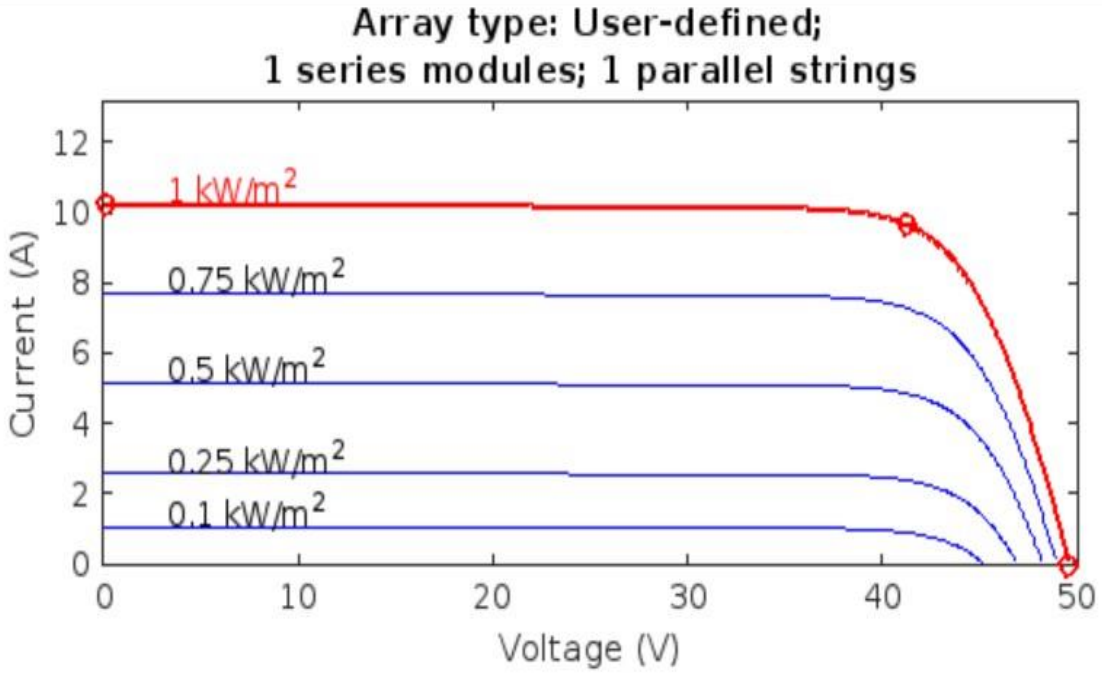


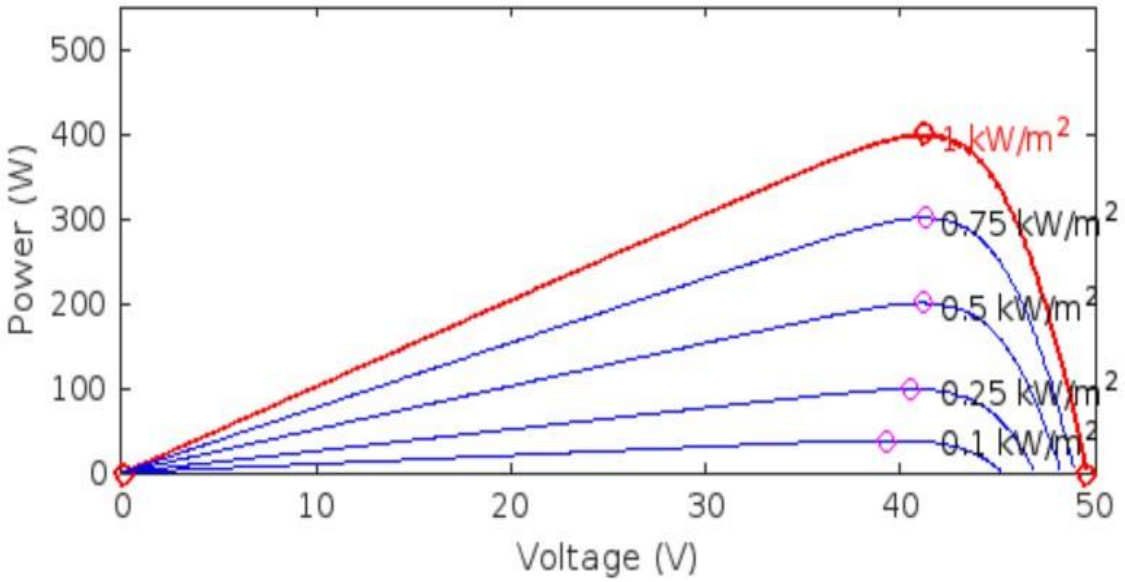
a) MATLAB Model for PV Array Simulation



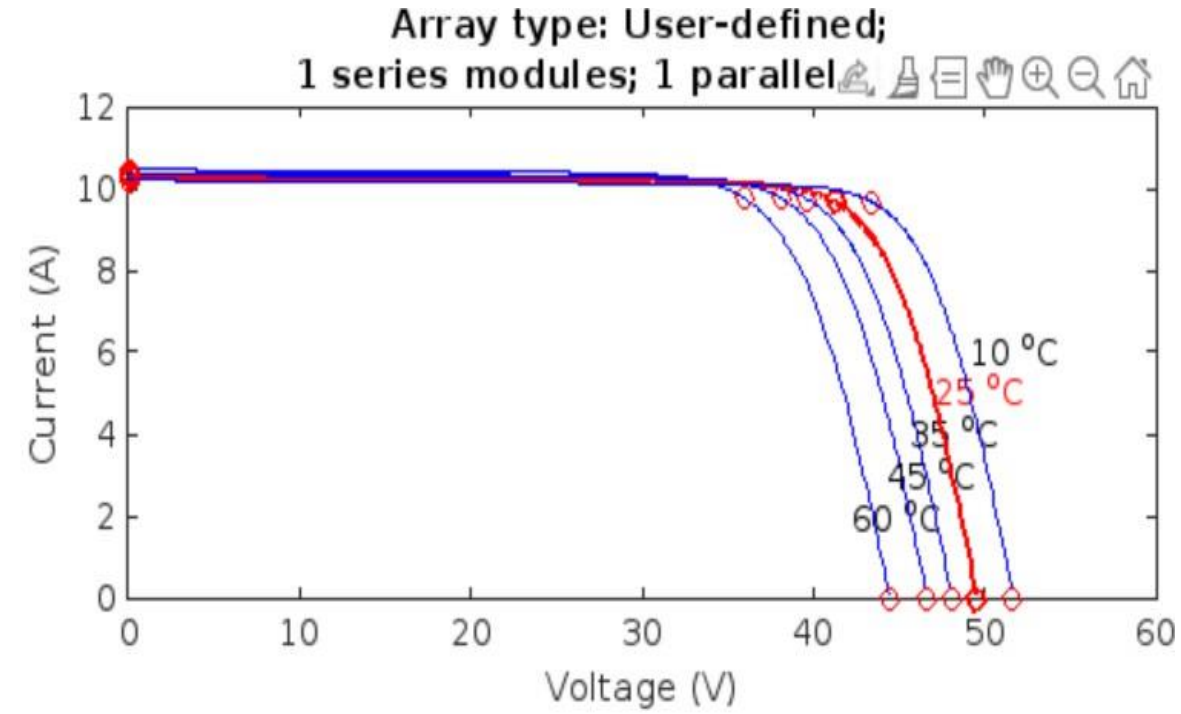
PV Cell Characteristics (IV Curves and PV Curves)

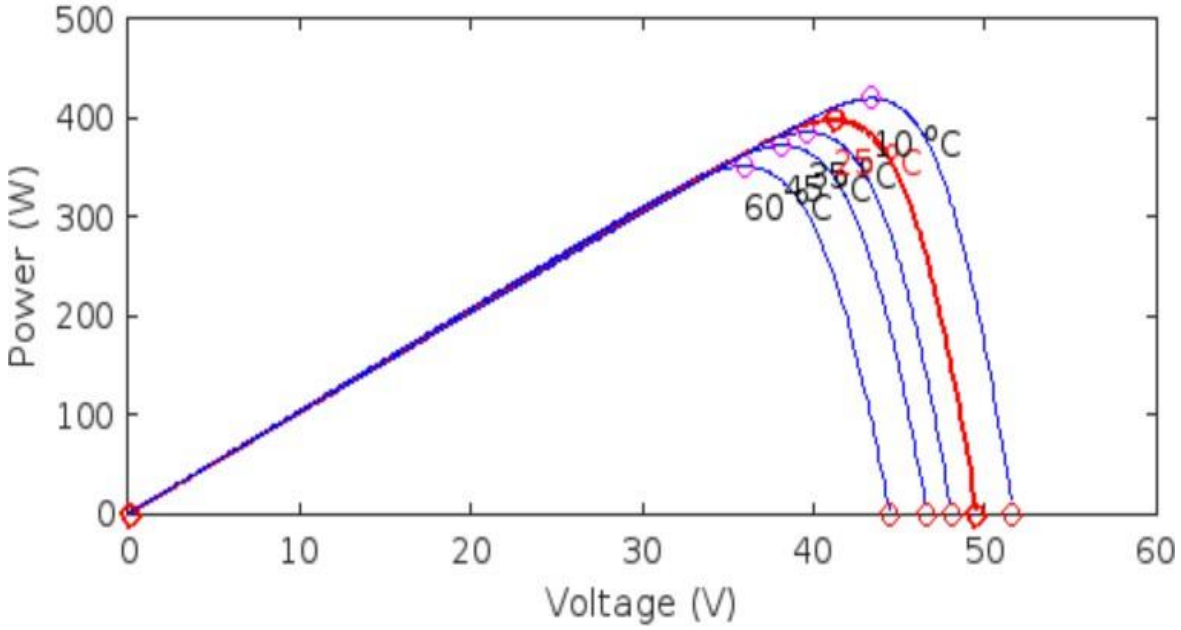
a) Constant Temperature of 25^0C and Varying Irradiance of 1000 W/m^2, 750 W/m^2, 500 W/m^2, 250 W/m^2, 100 W/m^2





b) Constant Irradiance of 1000 W/m2 with Varying Temperature of 60^0C, 45^0C, 35^0C, 25^0C, 10^0C





TASK -2

	Load(kW)	Hours(Hrs)	Energy(kWh)
Medical Equipment	1000	6	6000
Lighting	600	12	7200
HVAC Loads	2000	12	24000
Elevator, Escalator	200	6	1200
Other Equipment	400	5	2000
Total Energy Consumed in a day			40400

Solar PV System can Cater	0.05	
Total Energy consumed in day	40400	kWh
Solar PV is capable of supplying 5% of total connected load power requirement	2020	kWh
Number of Peak Sun Hours (location: Vellore) ref: Weather forecasting portal	5.31	h/day
Solar Panel Power Capacity	380	kW
By Considering 15% losses in the solar PV System	447	kW
Required Solar Panel Power Capacity	447	kW

Design of on-grid Solar PV System

S.No	Description	Value	Units
	Total Energy consumed in day	40400	kWh
	Solar PV is capable of supplying 5% of total connected load power requirement	2020	kWh
i	**Peak Sun Hours**		
	Number of Peak Sun Hours (location: Vellore) ref: Weather forecasting portal www.footprinthero.com	5.31	h/day
	Solar Panel Power Capacity	380	kWp
	By Considering 15% losses in the solar PV System	447	kWp
	Target Solar Capacity	447	kWp
ii	**Number of PV Modules Required**		
	Selected PV Panel Make	JA solar JAM72-S10-400-PR	
	Maximum Power(Pmax)	400	Wp
	Maximum Voltage(Vmp)	41.17	V
	Open Circuit Voltage(Voc)	49.5	V
	Maximum Current(Imp)	9.72	A
	Short Circuit Current(Isc)	10.26	A
	Total Number of Panels	1118	panels
iii	**Inverter Sizing**		
	Solar Panel Power Capacity	380	kWp
	Inverter Capacity with safety margin of 1.2	456	kW
	Inverter Make	Ingeteam 500 M275 Indoor (Pg. 45 refer)	
	Inverter Power	519	kW
	Inverter Minimum Voltage	443	V
	Inverter Maximum Voltage	820	V
	Maximum Current	1200	A
	Number of Inverters required	1	
iv	**Number panels in series**		
	Operating Voltage	820	V
	Number of Series Panels(Operating voltage/Voc)	17	
	Number of panels in a string	17	
v	**Number of strings**		
	Number of parallel strings(total panels/no of panels in string)	66	
	Sum of the short circuit currents from all the parallel strings (Number of Parllel strings*Isc)	677	A

Design of off-grid Solar PV System

S.No	Description	Value	Units
	Energy consumed by all the critical loads in a day	40400	kWh/day
	Solar PV is capable of supplying 5% of total connected load power requirement	2020	kWh
i	**Battery Sizing Calculation**		
	Battery Voltage	12	V
	Battery Rating	200	Ah
	Battery Losses	15	%
	Depth of Discharge(DoD)	80	%
	By accounting for 15% losses in battery, and 80% deep discharge factor, power required by battery	2971	kWh
	Number of days of Autonomy	2	days
	total energy to be delivered by battery pack	5942	kWh
	Battery Capacity(Total Energy/Battery Voltage)	495	kAh
	Number of Batteries required	2475	
ii	**Peak Sun Hours**		
	Number of Peak Sun Hours (location: Vellore) ref: Weather forecasting portal www.footprinthero.com	5.31	h/day
	Solar Panel Power Capacity	1119	kWp
	By Considering 15% losses in the solar PV System	1316	kWp
	Target Solar Capacity	1316	kWp
iii	**Number of PV Modules Required**		
	Selected PV Panel Make	JA solar JAM72-S10-400-PR	
	Maximum Power(Pmax)	400	Wp
	Maximum Voltage(Vmp)	41.17	V
	Open Circuit Voltage(Voc)	49.5	V
	Maximum Current(Imp)	9.72	A
	Short Circuit Current(Isc)	10.26	A
	Total Number of Panels	3290	panels
iv	**Inverter Sizing**		
	Solar Panel Power Capacity	1119	kWp
	Inverter Capacity with safety margin of 1.2	1343	kW
	Inverter Make	ABB PVS800 MWS 1 to 1.25MW inverter	
	Inverter Power	1250	kW
	Inverter Minimum Voltage	525	V
	Inverter Maximum Voltage	825	V
	Maximum Current	2290	A
	Number of Inverters required	1	
v	**Number panels in series**		
	Optimised Voltage	825	V

	Number of Series Panels(Operating voltage/Voc)	17	
	Number of panels in a string	17	
vi	**Number of strings**		
	Number of parallel strings(total panels/no of panels in string)	194	
	Sum of the short circuit currents from all the parallel strings (Number of Parllel strings*Isc)	1990	A
vii	**Number of batteries in series**		
	Battery Control Voltage	48	V
	Number of batteries in series	4	
	Number of batteries in parallel strings	619	

System Advisor Model Report

Detailed Photovoltaic	445 DC kW Nameplate	12.89, 79.14
Commercial	$1.72/W Installed Cost	UTC +5

Performance Model

Modules	
JA Solar JAM72S10-400/PR	
Cell material	Mono-c-Si
Module area	1.95 m²
Module capacity	400.46 DC Watts
Quantity	1,110
Total capacity	444.52 DC kW
Total area	2,164 m²

Inverters	
Custom (Inverter Datasheet Model)	
Unit capacity	519 AC kW
Input voltage	820 DC V
Quantity	1
Total capacity	519 AC kW
DC to AC Capacity Ratio	0.86
AC losses (%)	0.00

Array	
Strings	74
Modules per string	15
String Voc (DC V)	742.50
Tilt (deg from horizontal)	12.89
Azimuth (deg E of N)	180
Tracking	no
Backtracking	-
Self shading	no
Rotation limit (deg)	-
Shading	no
Snow	no
Soiling	yes
DC losses (%)	4.44

Performance Adjustments	
Availability/Curtailment	none
Degradation	none
Hourly or custom losses	none

Annual Results (in Year 1)	
GHI kWh/m²/day	5.31
POA kWh/m²/day	127.00
Net to inverter	727,000 DC kWh
Net to grid	691,000 AC kWh
Capacity factor	17.7
Performance ratio	0.78

Financial Model

Project Costs	
Total installed cost	$764,233
Salvage value	$0

Analysis Parameters	
Project life	25 years
Inflation rate	2.5%
Real discount rate	6.4%

Project Debt Parameters	
Debt fraction	100%
Amount	$764,233
Term	25 years
Rate	4%

Tax and Insurance Rates	
Federal income tax	21 %/year
State income tax	7 %/year
Sales tax (% of indirect cost basis)	5%
Insurance (% of installed cost)	0 %/year
Property tax (% of assessed val.)	0 %/year

Incentives	
Federal ITC	26%

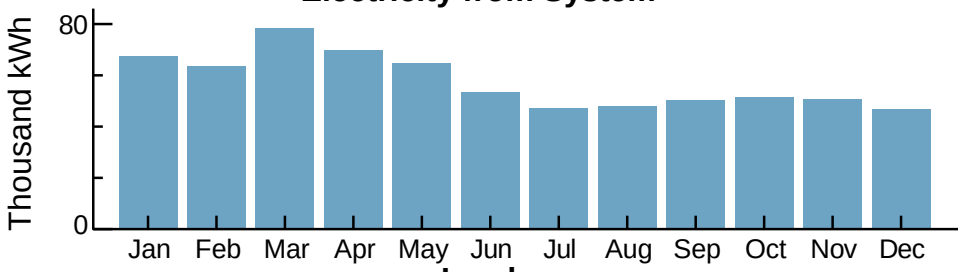
Electricity Demand and Rate Summary
Annual peak demand 274.2 kW
Annual total demand 726,208 kWh
Generic Commercial
Fixed charge: $30/month
Monthly excess with kWh rollover
Tiered TOU energy rates: 4 periods, 1 tier
Monthly TOU demand rates with tiers

Results	
Nominal LCOE	2.5 cents/kWh
Net present value	$253,100
Payback period	11.6 years

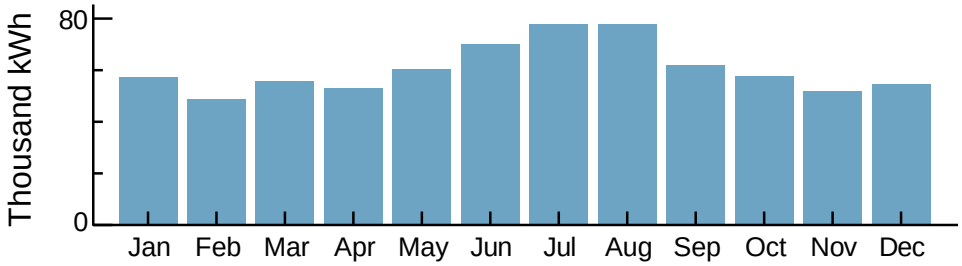
Detailed Photovoltaic Commercial	445 DC kW Nameplate $1.72/W Installed Cost	12.89, 79.14 UTC +5

Year 1 Monthly Generation and Load Summary

Electricity from System



Load



Year 1 Monthly Electric Bill and Savings ($)

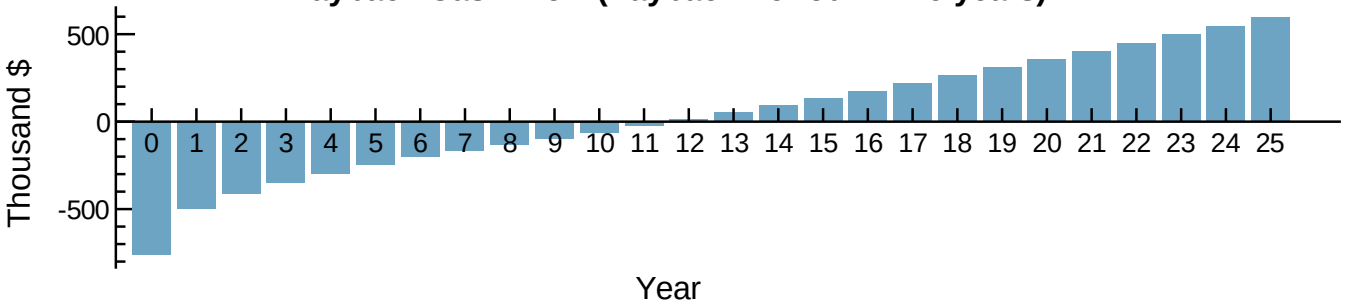
Month	Without System	With System	Savings
Jan	7,515	4,776	2,739
Feb	6,751	4,071	2,680
Mar	7,337	3,714	3,623
Apr	7,555	3,617	3,938
May	9,090	4,264	4,826
Jun	10,654	5,797	4,856
Jul	11,875	6,524	5,350
Aug	11,578	6,154	5,423
Sep	9,727	5,051	4,676
Oct	8,756	4,812	3,944
Nov	6,793	4,369	2,423
Dec	6,977	4,457	2,520
Annual	104,614	57,611	47,003

NPV Approximation using Annuities

Annuities, Capital Recovery Factor (CRF) = 0.1023		
Investment	$-0	Sum:
Expenses	$-57,600	$25,800
Savings	$41,300	NPV = Sum / CRF:
Energy value	$42,100	$253,000

Investment = Installed Cost - Debt Principal - IBI - CBI
Expenses = Operating Costs + Debt Payments
Savings = Tax Deductions + PBI
Energy value = Tax Adjusted Net Savings
Nominal discount rate = 9.06%

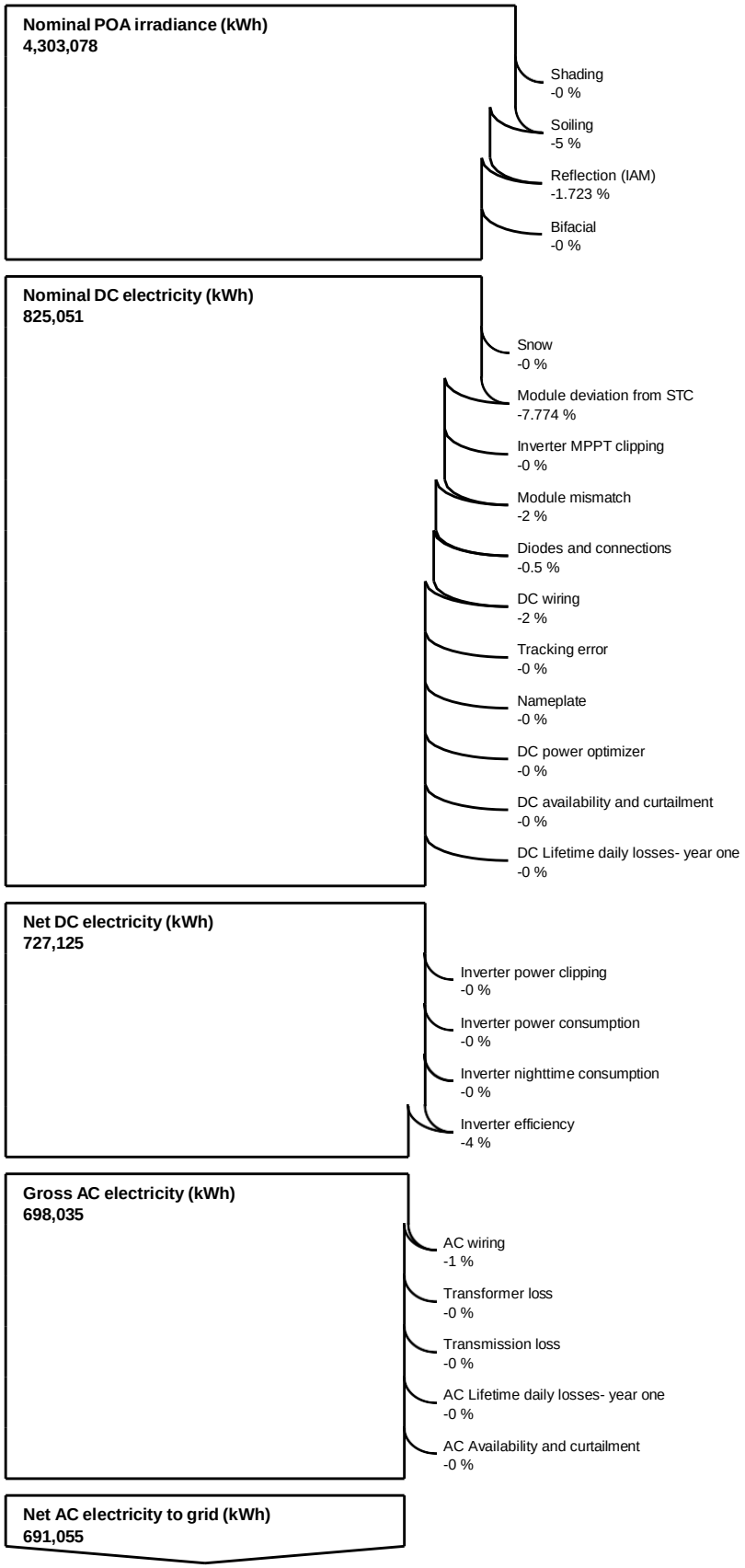
Payback Cash Flow (Payback Period = 11.6 years)



Detailed Photovoltaic
Commercial

445 DC kW Nameplate
$1.72/W Installed Cost

12.89, 79.14
UTC +5



Version 7.4.6

PVsyst - Simulation report

Grid-Connected System

Project: New Project

Variant: New simulation variant

No 3D scene defined, no shadings

System power: 1058 kWp

Chennai - India

Author

PVsyst V7.4.6
VC0, Simulation date:
25/03/24 11:31
with V7.4.6

Project summary

Geographical Site
Chennai
India

Situation

Latitude	13.09 °N
Longitude	80.28 °E
Altitude	33 m
Time zone	UTC+5.5

Project settings
Albedo 0.20

Weather data
Chennai
Meteonorm 8.1 (1996-2015) - Synthetic

System summary

Grid-Connected System
No 3D scene defined, no shadings

PV Field Orientation
Fixed plane
Tilt/Azimuth 13.8 / 0 °

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

System information

PV Array		Inverters	
Nb. of modules	2646 units	Nb. of units	1 unit
Pnom total	1058 kWp	Pnom total	982 kWac
		Pnom ratio	1.078

Results summary

Produced Energy	1656634 kWh/year	Specific production	1565 kWh/kWp/year	Perf. Ratio PR	82.85 %

Table of contents

General parameters

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation

Orientation		Sheds configuration	Models used	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	13.8 / 0 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

Horizon	Near Shadings	User's needs
Free Horizon	No Shadings	Unlimited load (grid)

PV Array Characteristics

PV module

Manufacturer	Generic
Model	JAM72-S10-400-PR
(Original PVsyst database)	
Unit Nom. Power	400 Wp
Number of PV modules	2646 units
Nominal (STC)	1058 kWp
Modules	147 string x 18 In series
At operating cond. (50°C)	
Pmpp	966 kWp
U mpp	671 V
I mpp	1438 A

Inverter

Manufacturer	Generic
Model	Ingecon Sun 1070TL B385 IP54 H1000
(Original PVsyst database)	
Unit Nom. Power	982 kWac
Number of inverters	1 unit
Total power	982 kWac
Operating voltage	552-820 V
Max. power (=>35°C)	1067 kWac
Pnom ratio (DC:AC)	1.08

Total PV power

Nominal (STC)	1058 kWp
Total	2646 modules
Module area	5310 m²

Total inverter power

Total power	982 kWac
Max. power	1067 kWac
Number of inverters	1 unit
Pnom ratio	1.08

Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 7.7 mΩ
Loss Fraction 1.5 % at STC

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.2 %

IAM loss factor
Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

PVsyst V7.4.6
VC0, Simulation date:
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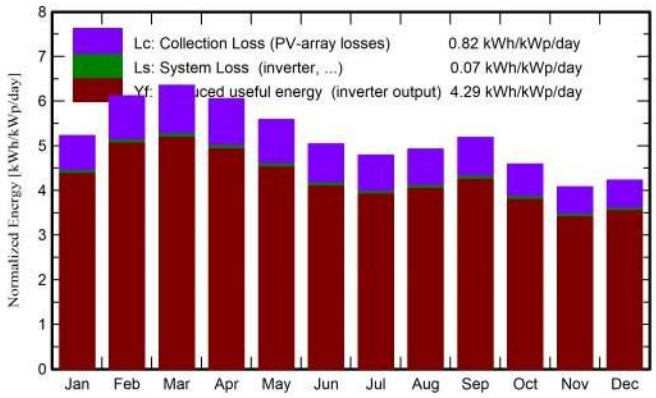
with V7.4.6

Main results

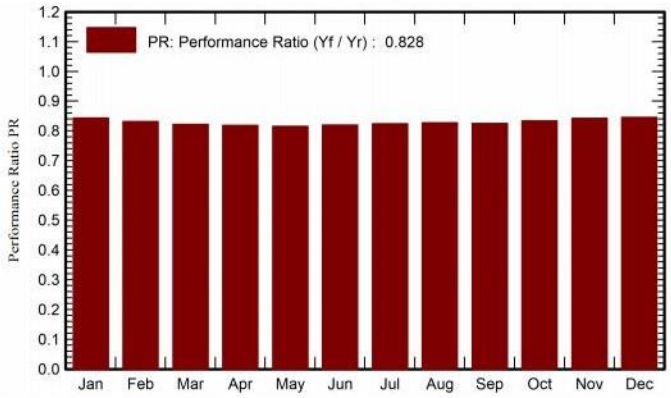
System Production

Produced Energy	1656634 kWh/year	Specific production	1565 kWh/kWp/year
		Perf. Ratio PR	82.85 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	144.2	66.34	25.11	162.1	157.6	146936	144758	0.844
February	156.4	60.48	26.21	171.3	167.0	153026	150818	0.832
March	189.7	74.75	28.44	197.0	192.0	173780	171261	0.822
April	184.7	81.63	30.16	181.6	176.5	159818	157490	0.819
May	182.6	91.28	32.17	173.2	167.7	151654	149441	0.815
June	162.3	84.47	31.21	151.2	146.0	133191	131164	0.820
July	158.0	91.47	30.64	148.5	143.3	131614	129553	0.824
August	157.1	89.71	29.68	152.8	148.2	135941	133832	0.827
September	153.7	78.01	28.85	155.7	151.2	138146	136026	0.826
October	135.0	74.43	27.86	142.3	138.4	127657	125615	0.834
November	112.4	62.00	25.92	122.5	119.0	111093	109271	0.843
December	117.7	64.21	25.22	131.1	127.4	119297	117405	0.846
Year	1853.9	918.79	28.47	1889.3	1834.3	1682153	1656634	0.828

Legends

GlobHor	Global horizontal irradiation
DiffHor	Horizontal diffuse 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
PR	Performance Ratio

PVsyst V7.4.6
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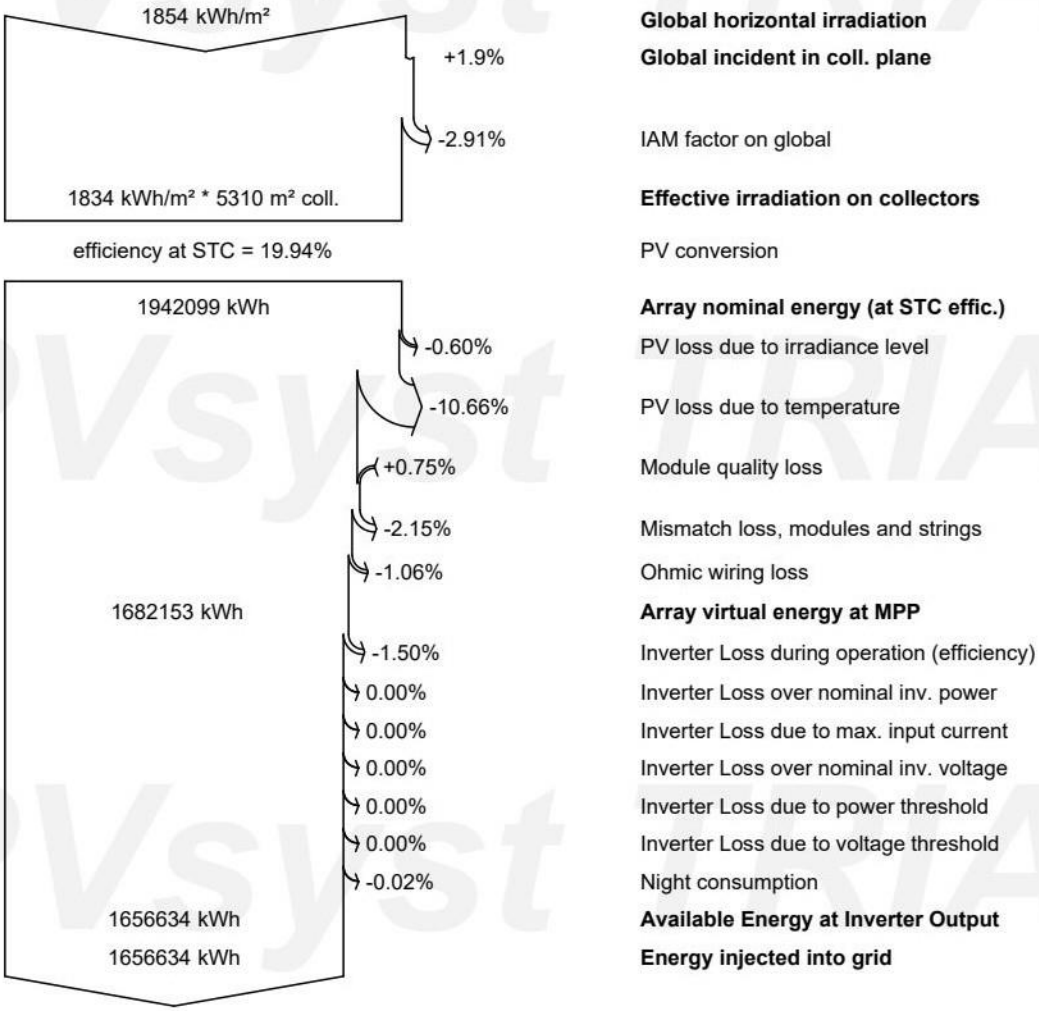
with V7.4.6

Loss diagram



PVsyst V7.4.6
VC0, Simulation date:
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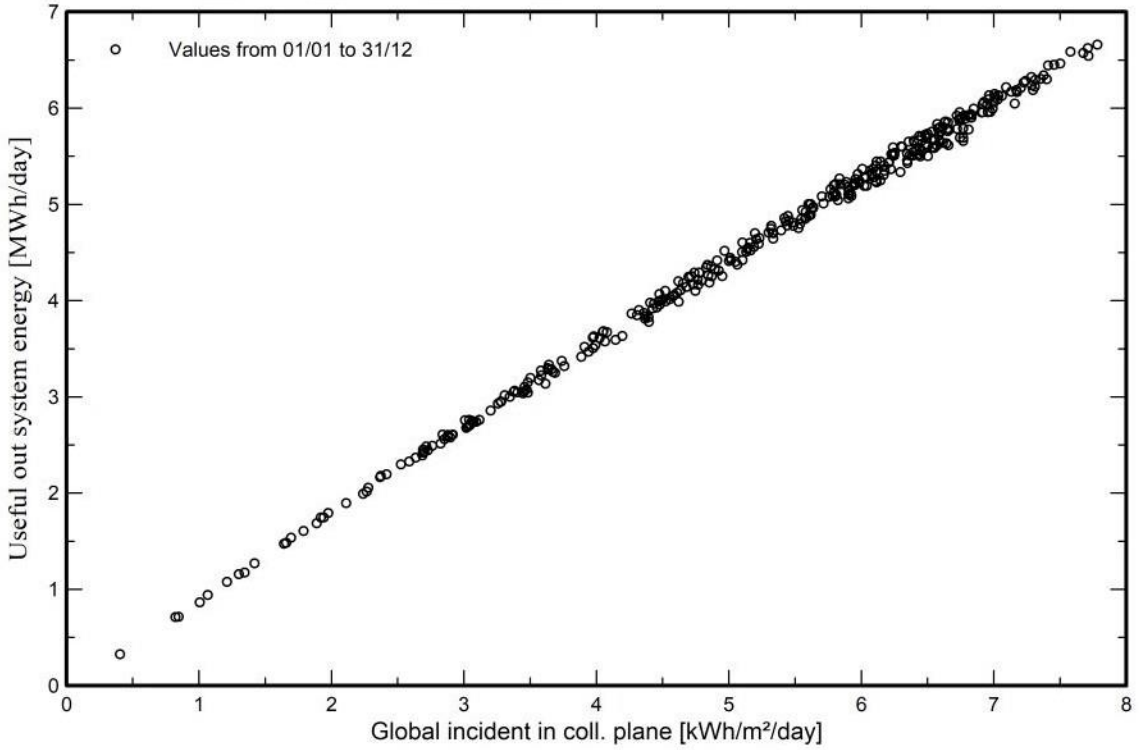
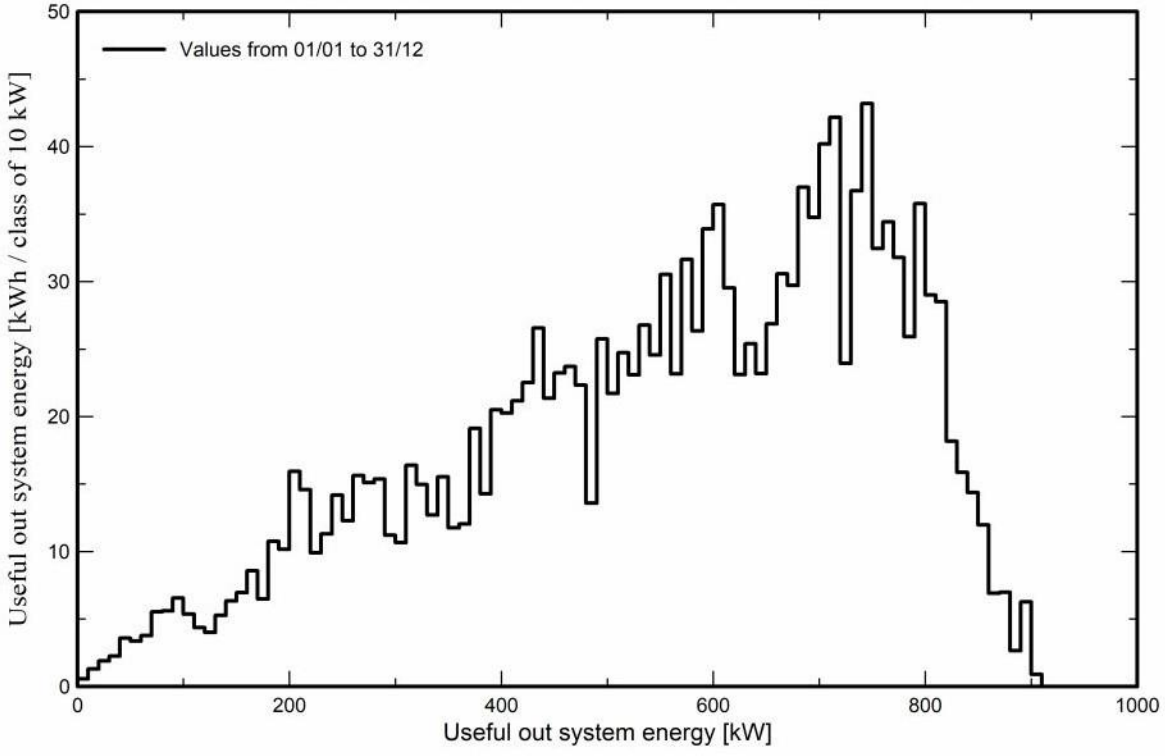
with V7.4.6

Predef. graphs

Daily Input/Output diagram



System Output Power Distribution



Single-line diagram

PVsyst V7.4.6
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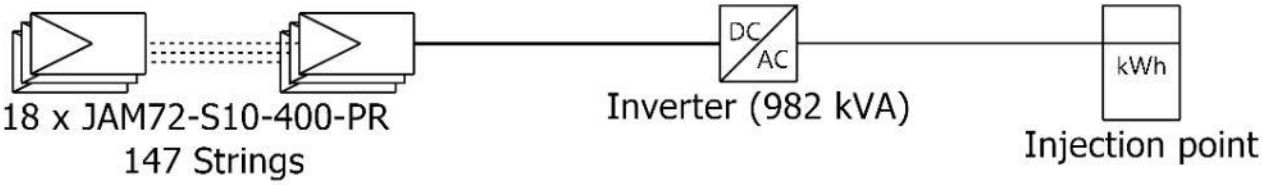
25/03/24 11:31
with V7.4.6



PV module	JAM72-S10-400-PR
Inverter	Ingecon Sun 1070TL B385 IP54 H1000
String	18 x JAM72-S10-400-PR

	New Project	
	VC0 : New simulation variant	25/03/24

LNT-SPV-06-Task 5

Solar PV Module Make:

400Wp JA Solar JAM72-S10-400-PR make

Solar PV Array Configuration:

66 Parallel string with 17 Series connected modules per string.

Design of Boost Converter

Duty Ratio = 50% = **0.5**

Switching Frequency = **25kHz**

Load Resistance = **10 ohm**

Lmin = $D(1-D)^2R / 2fs = 0.5(1–0.5)^2\ 10 / 2 \times 25k =$ **25 μH**

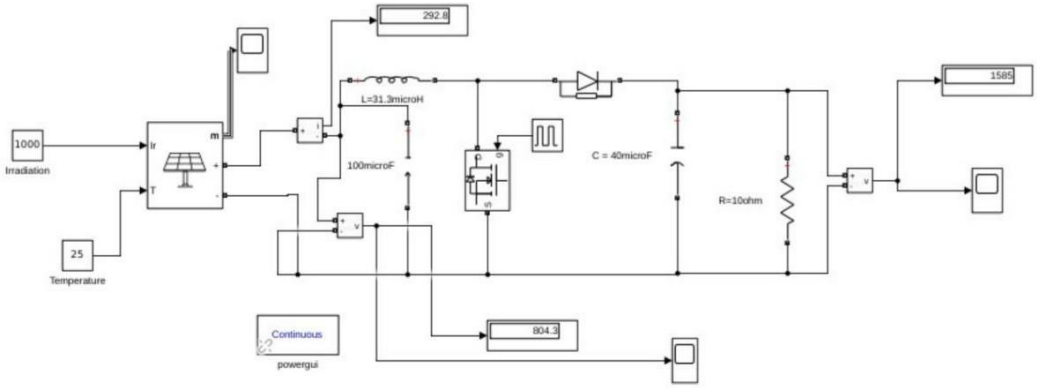
Assume 25% safety margin for L (for inductor current to be continuous)

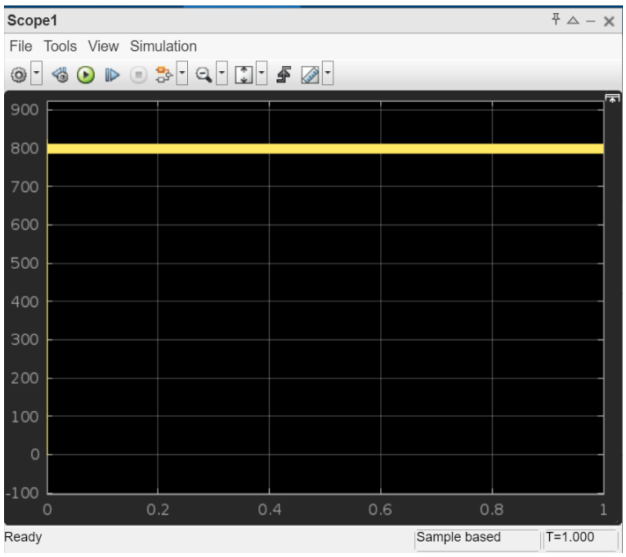
Lactual = 1.25 x Lmin = 1.25 x 25μH = **31.3 μH**

C = D / R (Ripple Factor) fs **=** $0.5 / (10 \times (0.05)\ (25 \times 10^3)) =$ **40μF**

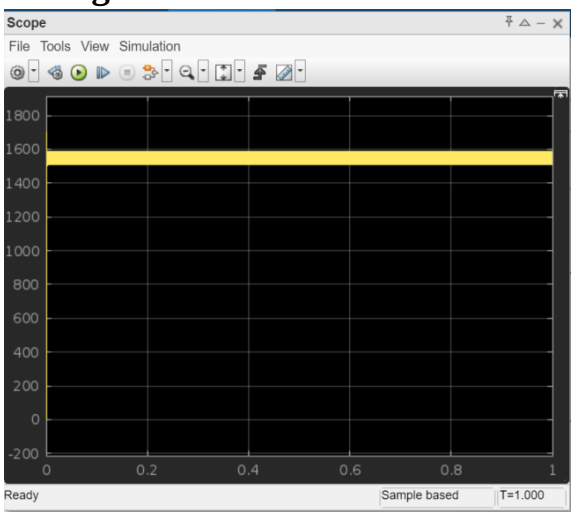
Capacitance connected across PV array = **100μF** (to suppress input voltage ripple and filter ripple current).

a) **MATLAB Model for PV Array with Boost Converter (for Constant Irradiation)**



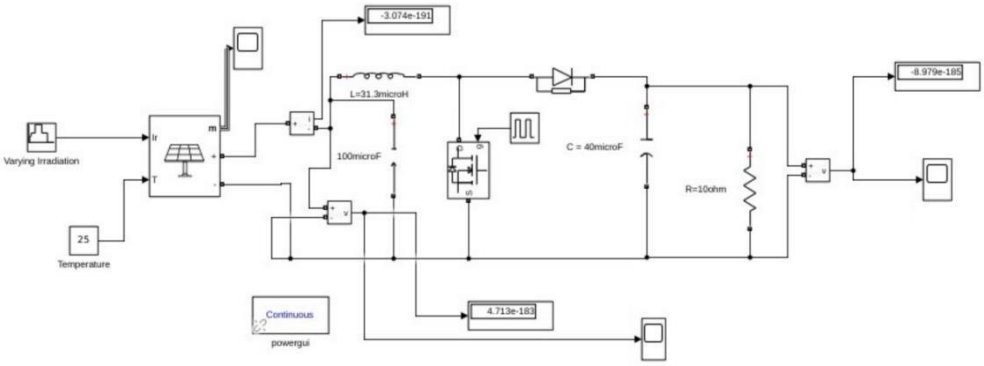


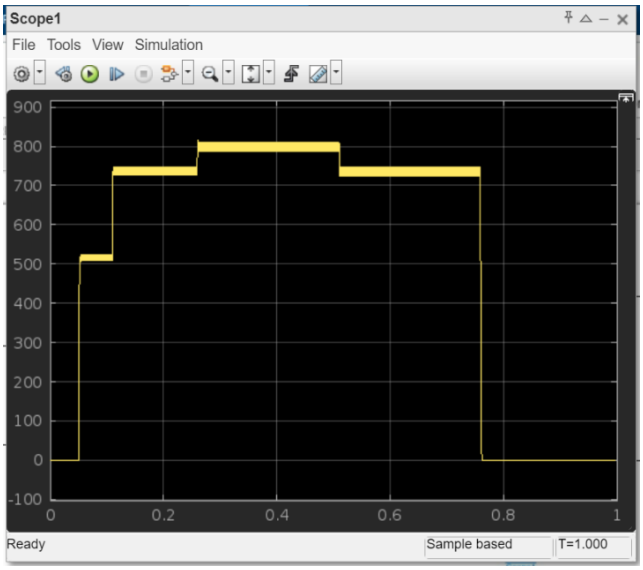
PV Output Voltage for Constant Irradiation of 1000 W/m2



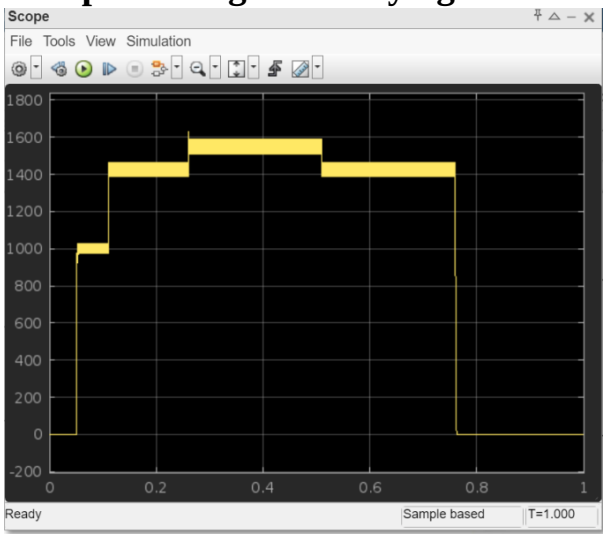
Boost Converter Output Voltage for Constant Irradiation of 1000 W/m2

b) MATLAB Model for PV Array with Boost Converter (for Varying Irradiation)





PV Output Voltage for Varying Irradiation



Boost Converter Output Voltage for Varying Irradiation