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Review on PVsyst - Simulation Report for Grid Connected Solar Power Systems

Mr. Posannapeta Y Ganga Ram
Ph.D. Research Scholar, Department of Electrical Engineering
Shri Venkateshwara University, Gajraula, India

Dr. Sharad Kumar
Head of the Department, School of Engineering & Technology
Shri Venkateshwara University, Gajraula, India

Abstract:
PVsyst is a design and simulation software for the study, sizing and data analysis of complete PV (Photo-Voltaic) systems. It deals with grid-connected, stand-alone and pumping PV systems, and includes extensive weather data and PV system components databases, as well as general solar energy tools.

In this article, it is described with currently existing actual 252.5 MWp (Mega-Watt peak DC-capacity) solar PV-power plant, with stagewise explanation with detailed screen-shoot parameters.

Key Words: PVsyst, Grid-connected, Stand-alone, Photovoltaic, PV systems, Array, Simulation, Losses.

1. INTRODUCTION

PVsyst is a comprehensive software tool designed for the simulation and analysis of photovoltaic systems. It allows users to design and optimize solar energy projects by providing detailed assessments of system performance, energy yields, and financial viability.

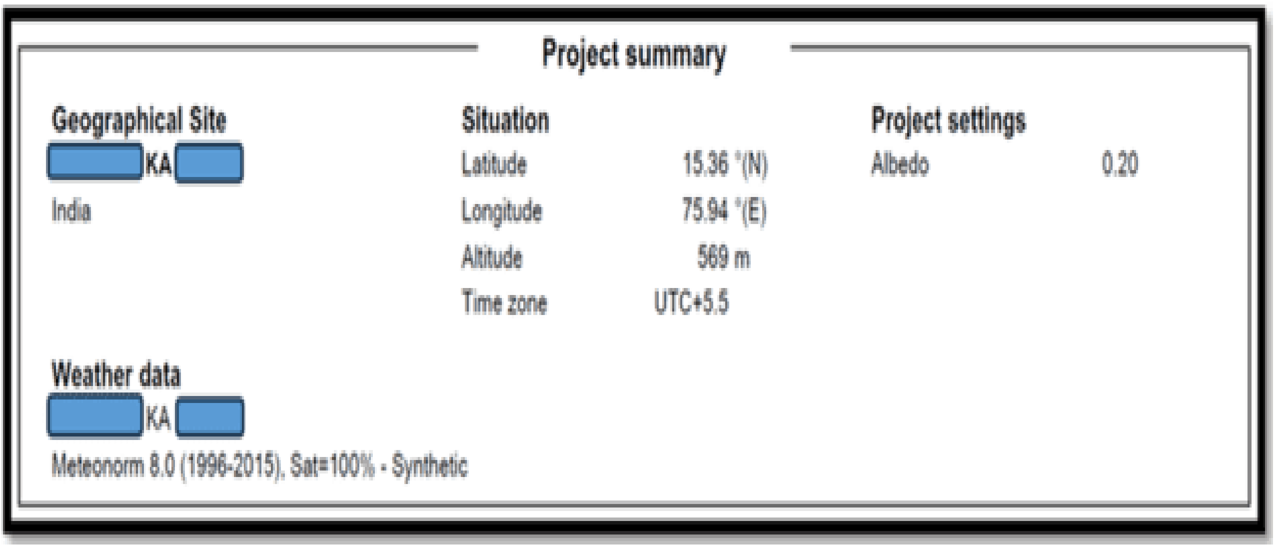

Fig.1: Project Summary with Geographical details & Whether data

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Here an example as taken for every-stage level explanation purpose, the plant capacity was 252.5 MWp DC input, and 192.3 MW AC Output grid connected plant, with single axis (i.e. East – West) trackers. Location of this existing plant is KA: Karnataka, India.

The Fig. 1 & Fig. 2 indicates that, project summary with geographical details & whether data and system summary details must feed into PVsyst-software to begin the system design.

System summary

Grid-Connected System		**Unlimited Trackers with backtracking**	
Orientation #1		**Near Shadings**	**User's needs**
Tracking horizontal axis		no Shadings	Unlimited load (grid)
Axis azimuth	0 °		
Phi min / max.	-/+ 52 °		
Tracking algorithm			
Astronomic calculation			
Backtracking activated			

System information

PV Array		**Inverters**	
Nb. of modules	441099 units	Nb. of units	50 units
Pnom total	252.5 MWp	Total power	220000 kWac
		Grid power limit	192.3 MWac
		Grid lim. Pnom ratio	1.313

Fig.2: System summary with tracker, PV array & Inverter details

2. DEFINE THE PROJECT

For System design: Rapidly design grid-connected, standalone, or pumping photovoltaic systems. The program guides to selecting components for sizing the project.

For System sizing: Visualize sizing constraints for modules and inverters, including I/V curves and power distribution, focusing on optimal inverter sizing and comprehensive loss analysis.

General parameters

Grid-Connected System		**Unlimited Trackers with backtracking**			
Orientation #1				**Models used**	
Tracking horizontal axis		**Field properties**		Transposition	Perez
Axis azimuth	0 °	Nb. of trackers	500 units	Diffuse	Perez, Meteonorm
Phi min / max.	-/+ 52 °	Unlimited trackers		Circumsolar	separate
Tracking algorithm		**Sizes**			
Astronomic calculation		Tracker Spacing	7.00 m		
Backtracking activated		Sensitive width	2.28 m		
		GCR Shading	32.9 %		
		Left inactive band	0.02 m		
		Right inactive band	0.02 m		
		Backtracking limit angle			
		Phi limits	+/- 70.6 °		
		Backtracking parameters			
		Backtracking pitch	7.00 m		
		Backtracking width	2.30 m		
		Left inactive band	0.02 m		
		Right inactive band	0.02 m		
		GCR Backtracking	32.9 %		
		Parameters choice	Automatic		

Fig.3: General parameters with tracker's backtracking details

With PVsyst, users can model various types of PV installations with location-specific climate data and component specifications, while considering factors such as shading effects on the system, battery storage, grid unavailability and panel degradation.

The Fig.3 & Fig. 4 indicates that, general parameters with tracker's backtracking details and some more additional general parameter (like: bifacial data, tracker orientations) details has given for design inputs, to get the simulation and results.

Horizon
Free Horizon

Near Shadings
no Shadings

User's needs
Unlimited load (grid)

Bifacial system definition
Orientation #1
Bifacial system

Model	Unlimited Trackers 2D model

Bifacial model geometry

Tracker Spacing	7.00 m
Tracker width	2.32 m
Axis height above ground	1.50 m
Nb. of sheds	500 units

Bifacial model definitions

Ground albedo average	0.15
Bifaciality factor	76 %
Rear shading factor	10.0 %
Rear mismatch loss	10.0 %
Shed transparent fraction	0.0 %

Grid power limitation

Active power	192.3 MWac
Pnom ratio	1.313

Limit applied at the injection point

Fig.4: Some more additional general parameter details

Orientations: Benefit from flexibility in project customization by defining unlimited orientations and explore the possibility of combining trackers and fixed plans in a single simulation.

Simulation and results: Calculate annual energy distribution, analyses key metrics such as total energy, yield, and specific energy, through detailed reports on gains and losses.

Monthly ground albedo values

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
0.14	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.14	0.15

Fig.5: Monthly albedo values

3. TYPES OF DIFFERENT TOOLS

Grid-connected, Stand-alone PV systems: Choose the type of system for simulation & design. Grid-connected involves generated energy from the photovoltaic array exports to grid lines, it improves energy management and reliability & stability of grid. Stand-alone is self-consumption involves the direct use of photovoltaic energy on the production site, minimising grid dependence and optimizing the use of solar energy, by storing the energy in battery banks.

Bifacial systems and trackers: Simulate bifacial installations and photovoltaic systems on single or dual-axis trackers, with safety and backtracking options.

Meteorological databases: Use on-board mapping to locate the project and automatically import meteorological data from databases: Meteonorm 8.2, NASA-SSE, PVGIS-TMY, NRELTMY, Solcast TMY, Solar Anywhere TGY, and Solargis. Many other formats can also be imported manually.

Ageing, optimization, and batch processing: Explore our suite of advanced tools providing detailed results for advanced design decisions. Combine multi-year batch simulation for serialised simulations, including row spacing and bifacial height adjustments, and photovoltaic module ageing.

Components: Access a verified and regularly updated database including photovoltaic panels, inverters, batteries, pumps, and optimizers (AMPT, Huawei, Maxim, Sungrow, SolarEdge, TIGO) for realistic simulations.

PV Array Characteristics

Array #1 - PV Array

PV module		**Inverter**	
Manufacturer	TP Solar Limited	Manufacturer	Sungrow
Model	TP570HG10NB	Model	SG4400UD-20
(Custom parameters definition)		(Custom parameters definition)	
TPSL_TP570HG10NB_04022025.PAN		Unit Nom. Power	4400 kWac
Unit Nom. Power	570 Wp	Number of inverters	18 units
Number of PV modules	159192 units	Total power	79200 kWac
Nominal (STC)	90.74 MWp	Operating voltage	950-1300 V
Modules	5896 string x 27 In series	Max. power (=>20°C)	5280 kWac
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.15
Pmpp	83.91 MWp		
U mpp	1095 V		
I mpp	76660 A		

Fig.6: PV Array characteristics of PV Array #1

Array #2 - Sub-array #2

PV module		**Inverter**	
Manufacturer	TP Solar Limited	Manufacturer	Sungrow
Model	TP565HG10NB	Model	SG4400UD-20
(Custom parameters definition)		(Custom parameters definition)	
TPSL_TP565HG10NB_04102024.PAN		Unit Nom. Power	4400 kWac
Unit Nom. Power	565 Wp	Number of inverters	6 units
Number of PV modules	54000 units	Total power	26400 kWac
Nominal (STC)	30.51 MWp	Operating voltage	950-1300 V
Modules	2000 string x 27 In series	Max. power (=>20°C)	5280 kWac
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.16
Pmpp	28.21 MWp		
U mpp	1089 V		
I mpp	25905 A		

Fig.7: PV Array characteristics of PV Array #2

In this project, it is used four types of PV-arrays with TP565HG 10NB, TP570HG 10NB, TP575HG 10NB and TP580HG 10NB of PV-modules, Fig. 6 to Fig. 9 PV-Array characteristics is indicated. In fig. 10 Total PV-Power with inverter's power details are indicated.

Array #3 - Sub-array #3			
PV module		**Inverter**	
Manufacturer	TP Solar Limited	Manufacturer	Sungrow
Model	TP575HG10NB	Model	SG4400UD-20
(Custom parameters definition)		(Custom parameters definition)	
TPSL_TP575HG10NB_04102024.PAN		Unit Nom. Power	4400 kWac
Unit Nom. Power	575 Wp	Number of inverters	22 units
Number of PV modules	193320 units	Total power	96800 kWac
Nominal (STC)	111.2 MWp	Operating voltage	950-1300 V
Modules	7160 string x 27 In series	Max. power (=>20°C)	5280 kWac
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.15
Pmpp	102.8 MWp		
U mpp	1100 V		
I mpp	93441 A		

Fig.8: PV Array characteristics of PV Array #3

Array #4 - Sub-array #4			
PV module		**Inverter**	
Manufacturer	TP Solar Limited	Manufacturer	Sungrow
Model	TP580HG10NB	Model	SG4400UD-20
(Custom parameters definition)		(Custom parameters definition)	
TPSL_TP580HG10NB_04022025.PAN		Unit Nom. Power	4400 kWac
Unit Nom. Power	580 Wp	Number of inverters	4 units
Number of PV modules	34587 units	Total power	17600 kWac
Nominal (STC)	20.06 MWp	Operating voltage	950-1300 V
Modules	1281 string x 27 In series	Max. power (=>20°C)	5280 kWac
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.14
Pmpp	18.55 MWp		
U mpp	1106 V		
I mpp	16778 A		

Fig.9: PV Array characteristics of PV Array #4

Total PV power		**Total inverter power**	
Nominal (STC)	252469 kWp	Total power	220000 kWac
Total	441099 modules	Max. power	264000 kWac
Module area	1139470 m²	Number of inverters	50 units
Cell area	1051989 m²	Pnom ratio	1.15

Fig.10: Total PV Power & Total inverter power details

4. PROJECT DESIGN AND SIMULATIONS

Project design and simulation is the main part of the software and is used for the complete study of a project. It involves the choice of meteorological data, system design, shading studies, losses determination, and economic evaluation.

The simulation is performed over a full year in hourly steps and provides a complete report and many detailed results. Within the project design and simulation section, PVsyst allows to create and simulate three types of systems are Grid-Connected systems, stand-alone systems and solar pumping systems.

IAM loss factor - Array #1
Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.981	0.909	0.854	0.766	0.600	0.000

IAM loss factor - Array #2
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.963	0.892	0.814	0.679	0.438	0.000

IAM loss factor - Array #3
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.963	0.892	0.814	0.679	0.438	0.000

IAM loss factor - Array #4
Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	0.981	0.909	0.854	0.766	0.600	0.000

Fig.11: IAM loss factor Array #1 to Array #4

The IAM (Incidence Angle Modifier) loss factor, it represents the energy loss due to sunlight reflecting off the panel surface rather than passing through, occurring primarily when sun rays hit at an angle. Typical IAM losses for standard silicon solar panels are low, usually ranging between 2–4% of annual output. Fig.11: IAM loss factor Array #1 to Array #4 shown.

Array losses

Array Soiling Losses
Loss Fraction 2.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

LID - Light Induced Degradation
Loss Fraction 1.5 %

Module Quality Loss
Loss Fraction 0.00 %

Module mismatch losses
Loss Fraction 0.60 % at MPP

Strings Mismatch loss
Loss Fraction 0.10 %

IAM loss factor - Array #1
Incidence effect (IAM): User defined profile

Fig.12: Array losses details

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System losses

Unavailability of the system		Auxiliary losses	
Time fraction	0.7 %	Proportional to Power	3.0 W/kW
	2.5 days,	0.0 kW from Power thresh.	
	3 periods		

Fig.13: System losses details

The array losses and the system losses are shown in Fig. 12 & Fig. 13, and the AC wiring losses along with AC losses in transformers also shown in Fig. 14 and Fig.15.

AC wiring losses

Inv. output line up to MV transfo	
Inverter voltage	660 Vac tri
Loss Fraction	0.20 % at STC
Inverter: SG4400UD-20	
Wire section (50 Inv.)	Copper 50 x 3 x 3000 mm²
Average wires length	28 m
MV line up to Injection	
MV Voltage	33 kV
Wires	Copper 3 x 3000 mm²
Length	1920 m
Loss Fraction	0.27 % at STC

Fig.14: AC wiring losses details

AC losses in transformers

MV transfo	
Medium voltage	33 kV
Transformer parameters	
Nominal power at STC	248.0 MVA
Iron Loss (24/24 Connexion)	495.94 kVA
Iron loss fraction	0.20 % at STC
Copper loss	3223.58 kVA
Copper loss fraction	1.30 % at STC
Coils equivalent resistance	3 x 0.02 mΩ

Fig.15: AC losses in Transformer details

PVsyst Main Results: These are the key performance indicators (KPIs) of the power system are,

- **Produced Energy (P50, P90):** The estimated annual energy output, with P50 being the average and P90 the conservative, bankable value.
- **Specific Production:** Annual energy produced per installed capacity (kWh/kWp/year).
- **Performance Ratio (PR)**: A crucial KPI of system quality (actual generation vs. ideal generation).
- **Loss Diagram**: A graphical representation of losses (shading, irradiance, temperature, cable, inverter, etc.).

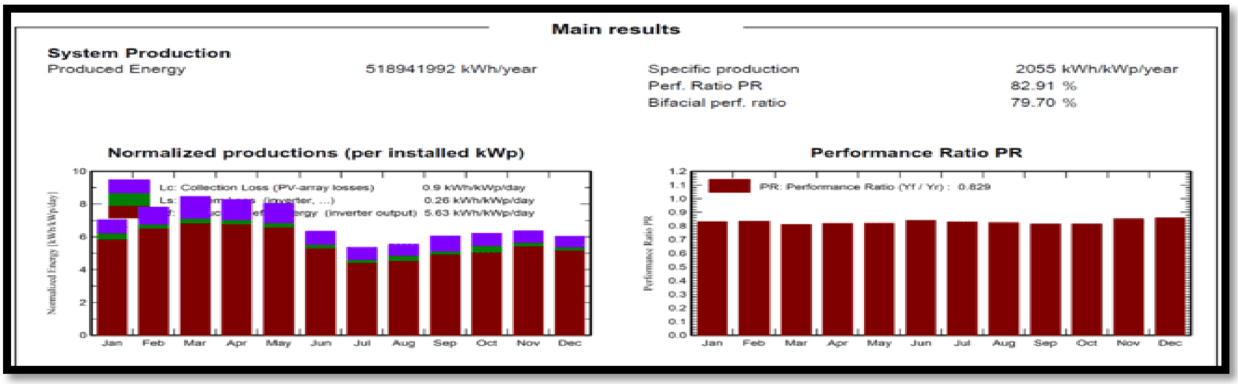

Fig.16: Main results with system production & PR details

Balances and Main Results Table: This table breaks down simulation values, typically monthly basis,

- **Irradiation:** Global Horizontal (GlobHor), Diffuse (DiffHor), and Global Effective (GlobEff) plane of array.
- **Temperature:** Ambient temperature (T_Amb), impacting module efficiency.
- **Energy Generation:** (DC energy produced by panels) and (AC energy delivered to the grid).
- **Normalized Production:** Normalized performance factors per kilowatt peak (h/day or kWh/kWp/day).

Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR	PRBifi
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	ratio	ratio
January	163.7	46.70	23.35	218.6	209.6	48849480	45860058	0.831	0.804
February	166.7	49.90	25.91	218.9	210.4	47908017	46123712	0.835	0.806
March	202.2	66.50	28.69	262.6	252.8	55916985	53817220	0.812	0.783
April	195.8	79.70	29.18	248.5	238.8	53477385	51459220	0.820	0.788
May	200.1	83.70	28.67	249.8	239.7	53835638	51817163	0.822	0.789
June	159.9	83.30	25.18	190.7	181.9	42102371	40521126	0.842	0.805
July	139.9	75.90	24.77	165.7	157.9	36163727	34715755	0.830	0.792
August	146.5	88.70	24.21	171.6	163.2	38259989	35736335	0.825	0.787
September	149.1	76.70	24.37	181.6	173.2	38911667	37420016	0.816	0.781
October	152.6	69.90	25.08	192.6	184.2	42846572	39701502	0.816	0.785
November	147.6	48.60	23.82	191.4	183.7	42863463	41229102	0.853	0.823
December	145.0	53.40	22.74	187.0	178.7	42111634	40540785	0.859	0.829
Year	1969.1	822.99	25.49	2479.1	2373.9	543246927	518941992	0.829	0.797

Fig.17: Monthly Main results

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Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane	PRBifi	Bifacial Performance Ratio
GlobEff	Effective Global, corr. for IAM and shadings		

5. PVSYST LOSS DIAGRAM

The PVsyst loss diagram is a crucial, visual tool in simulation reports that breaks down energy flow from global horizontal irradiation to final grid injection, identifying specific losses along the way. It displays annual or monthly losses as percentages of previous energy levels—such as shading, temperature, and inverter efficiencies—to help users evaluate system design quality.

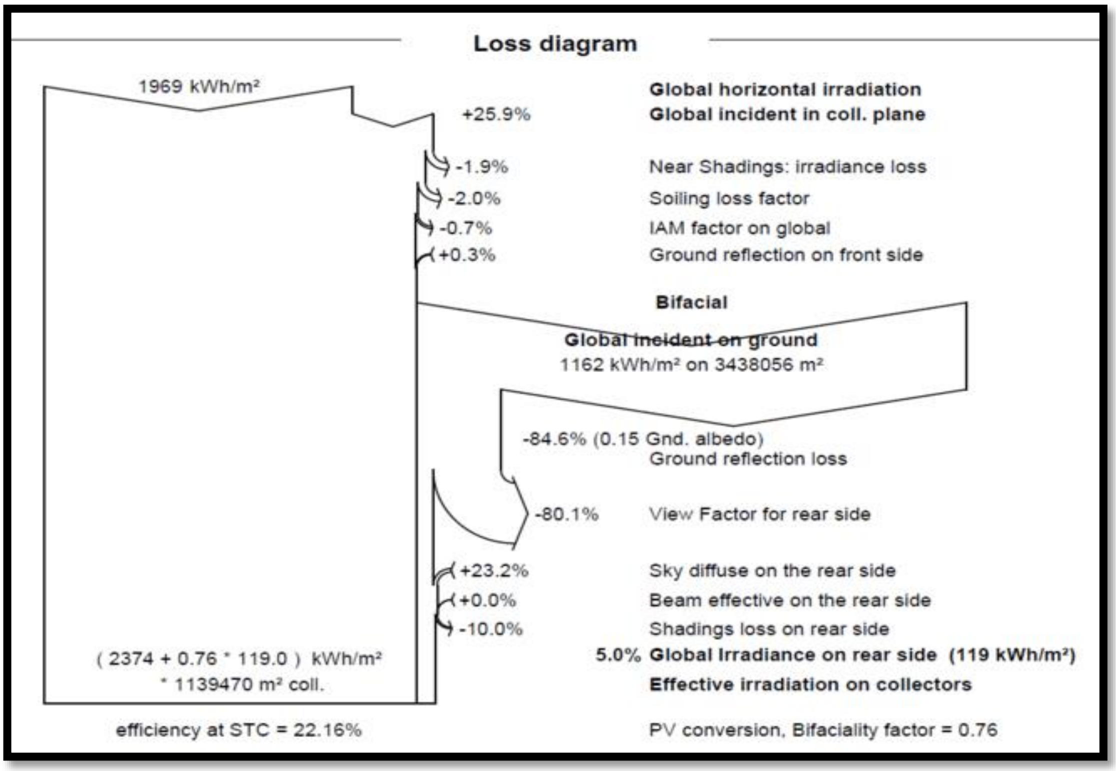

Fig.18: Loss diagram with bifacial factors

Key Components of the Loss Diagram: The diagram follows a logical path, dividing energy losses into optical and electrical stages:

- **Irradiation to Effective Energy**: Starts with global horizontal irradiance (GHI) and moves to Global Tilted Irradiance (GTI), accounting for shadings and incident angle modifier (IAM) losses.
- **Array Losses (DC Side):** Thermal Loss: Power loss due to cell temperatures rising above
- **Module Quality & LID:** Losses from manufacturing tolerances and Light-Induced Degradation (typically 1%- 4%).

- **Mismatch & Wiring:** Efficiency differences between modules and Ohmic losses in DC cables.
- **Inverter Losses (AC Side):**
- **Efficiency:** Losses during DC to AC conversion.
- **Clipping/Power Limiting:** Losses occurring when DC power exceeds inverter rating.
- **Final Output:** The final, useful energy injected into the grid.

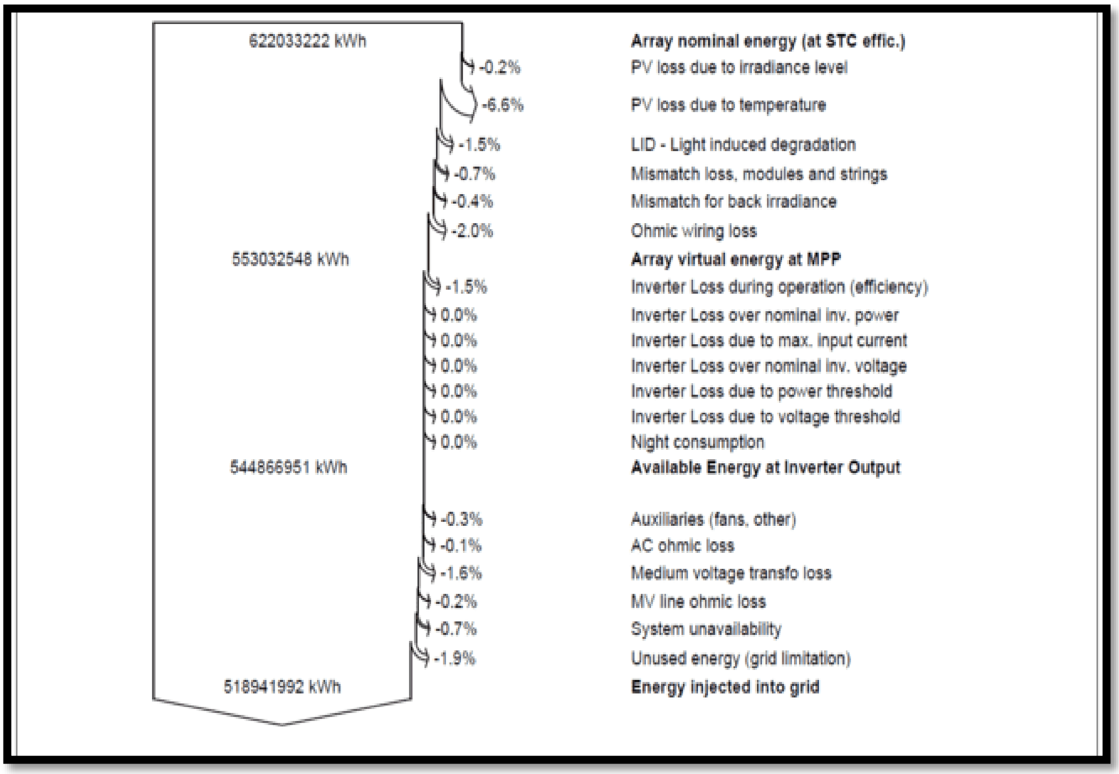

Fig.19: Total kWh-unit's losses up to energy injected into grid

Important Considerations

- **Not Additive Percentages:** Each loss is calculated based on the energy remaining from the previous stage, not the initial total energy.
- **Seasonal Analysis:** The diagram can be viewed monthly to identify high-loss periods.
- **Bifacial Systems:** For bifacial projects, the diagram includes additional energy gained from rear-side reflection.
- **Ohmic Losses:** These are calculated hourly, and typically in annual results, they equal about 60% of the designated nominal wiring loss fraction.

6. P50 & P90 EVALUATION

P50 and P90 are statistical confidence levels for solar power plant energy generation. P50 is the median "best estimate" with a 50% chance of being exceeded, used for expected revenue. P90 is a conservative estimate with a 90% chance of being exceeded (10% risk of underproduction), used by lenders to determine debt serviceability.

P50 - P90 evaluation

Weather data		Simulation and parameters uncertainties	
Source	Meteonorm 8.0 (1996-2015), Sat=100%	PV module modelling/parameters	1.0 %
Kind	TMY, multi-year	Inverter efficiency uncertainty	0.5 %
Year-to-year variability(Variance)	3.0 %	Soiling and mismatch uncertainties	2.0 %
Specified Deviation		Degradation uncertainty	1.0 %
Climate change	0.0 %		
Global variability (weather data + system)		**Annual production probability**	
Variability (Quadratic sum)	3.9 %	Variability	20.3 GWh
		P50	518.9 GWh
		P90	493.0 GWh
		P75	505.3 GWh

Fig.20: P50 – P90 Evaluation details

Key Differences: P50 vs. P90

- **P50 (Median Prediction):** Used for performance targeting, operational planning, and determining the most likely return on equity.
- **P90 (Risk Management):** Used by banks and financial institutions for financial modelling to ensure that even in a low-resource year, the project generates enough cash flow to cover debt payments.

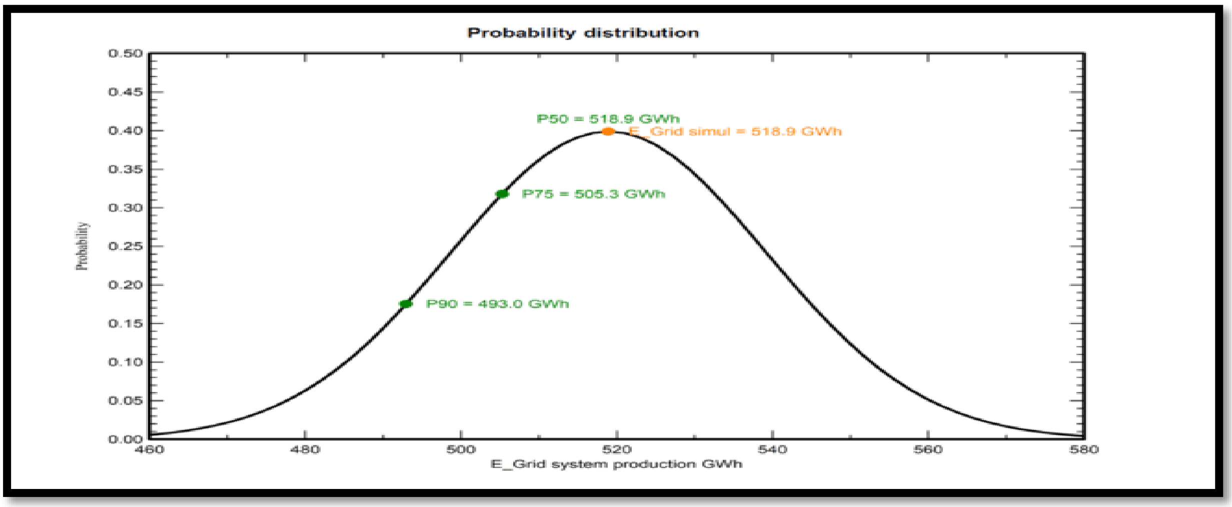

Fig.21: Probability distribution for P50 – P90

P50 and P90 are calculated from meteorological data (GHI, weather variability) and PV system simulations (e.g., using software like PVSyst). The process involves calculating the mean (P50) and then calculating P90 based on the volatility and uncertainty of the solar resource.

PVsyst single line diagram (SLD): It contains PV module strings, inverters and transformer. The total plant SLD shown in Fig. 22 and PV module's, inverter's & string details of total project shown in fig. 23.

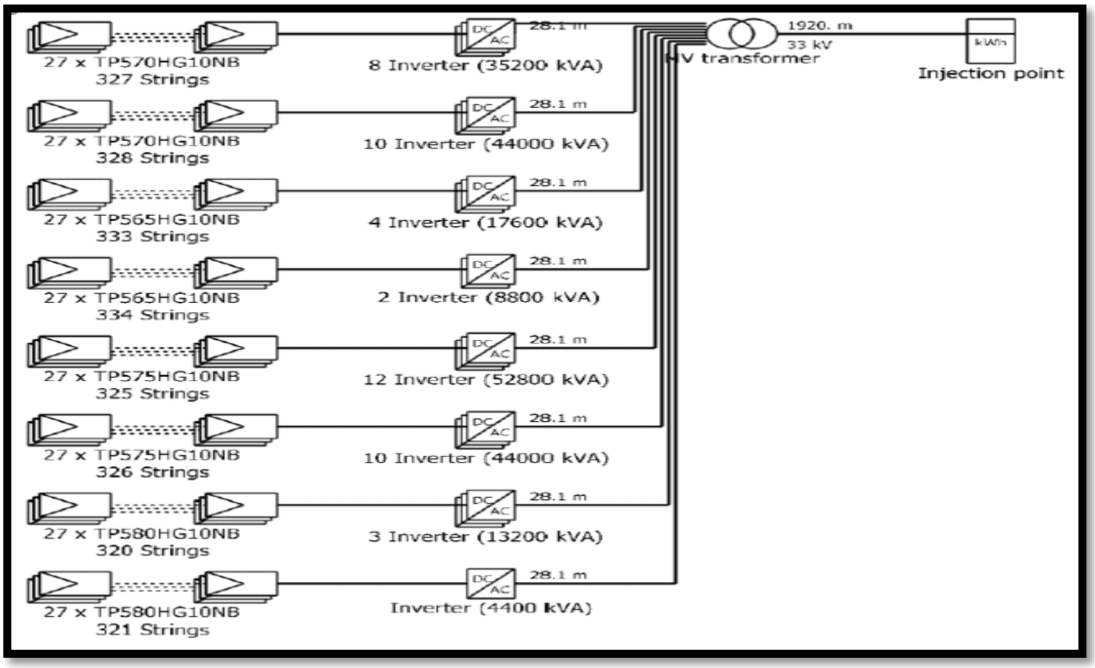

Fig.22: Single Line Diagram for Total Project

PV module 1	TP570HG10NB
PV module 2	TP565HG10NB
PV module 3	TP575HG10NB
PV module 4	TP580HG10NB
Inverter	SG4400UD-20
String 1	27 x TP570HG10NB
String 2	27 x TP565HG10NB
String 3	27 x TP575HG10NB
String 4	27 x TP580HG10NB

Fig.23: PV module's, inverter's & string details of total project

7. Results Summary (PVsyst simulation):

It summarizes a solar project's performance, primarily through a generated Report and a visual Loss Diagram. Key metrics include total annual energy production (E Grid): 51,89,41,992 units (i.e. kWh/year), specific production: 2055 kWh/kWp/year, and the performance ratio (PR): 82.91%, which measures system efficiency against solar resource availability, and Bifacial performance ratio: 79.7%, shown in Fig. 24.

Results summary

Produced Energy	518941992 kWh/year	Specific production	2055 kWh/kWp/year	Perf. Ratio PR	82.91 %
				Bifacial perf. ratio	79.70 %

Fig.24: Results summary details

8. CONCLUSION:

The PVsyst has just four simple steps to design a solar PV-system, those are,

- **Define Project / Site:** Just select the location and the meteorological data file.
- **Orientation:** Set the tilt and azimuth angles of the panels.
- **System Design:** Define the PV modules, inverters, and array configuration.
- **Simulation & Reporting:** Run the simulation and export the results/report.

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ABOUT AUTHORS:

Mr. Posannapeta Y Ganga Ram, he received Diploma in Electrical & Electronics engineering from S. S. Govt. Polytechnic, Zahirabad (India), B.Tech. (EEE) from J N T University, Hyderabad (India) and master's degree (M. Tech, Specialization in Elect. Power System Control) from Mysore (India). Mr. Ganga Ram, currently Ph.D. research scholar of Shri Venkateshwara University (SVU), Gajraula (India).

Dr. Sharad Kumar, Head of the Department, School of Engineering & Technology at Shri Venkateswara University (SVU), Gajraula. Graduated in ECE from UPTU, Lucknow (India), M. Tech Degree in ECE from Amity University, Noida (India) and Ph.D. in 2019 from SVU. Extensive experience in both theoretical and practical aspects of antenna design, electromagnetic wave propagation, RF systems engineering.