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Comparison of different PV power simulation softwares: case study on performance analysis of 1 MW grid-connected PV solar power plant

Najibhamisu Umar[1*], Birinchi Bora[2], Chandan Banerjee[2], B. S. Panwar[1]
[1]Sharda University,Greater Noida (NCR, Delhi) - 201306, INDIA
[2]National Institute of Solar Energy, Gurugram, India
Corresponding auther: Najibhamisu Umar

Abstract:*Several simulation softwares have been developed to simulate and optimize photovoltaic system. Engineers and Researchers used these simulation tools for sizing of PV power plant, pre-feasibility analysis, and optimization, technical and economic analysis in order to avoid system over-size, poor reliability, and high installation cost. In this paper, 10 simulation softwares with their main features and developers of these tools are discussed, the softwares studied are SAM, PVsyst, HOMER, PV*SOL, RETScreen, Solarius PV, HelioScope, Solar Pro, SOLARGIS, and PV F-Chart. The main objectives of this paper are to highlight researchers to identify the suitable software for research analysis and to perform degradation and performance analysis of PV power plant. A case study on performance analysis of I MW grid-connected PV solar power plant has been carried out using these simulation tools. Simulation results are then compared with actual data of the power plant to identify the suitable and most effective softwares for research and development. The annual average Performance Ratio (PR) and Capacity Utilization Factor (CUF) were found to be 0.7737 and 14.57% respectively.The PR was then used to determine the annual degradation rate of the PV plant which is found to be 0.98%/year. The defects in the power plant were analyzed to identify various degradation modes of PV modules. Encapsulant discoloration, glass shattering and deposited dust have been seen in few modules. The current status, abilities, limitations, and availability of all the software have also been presented. Homer, SAM, RETScreen and PVsyst are found to be the best and suitable software for performance analysis. There is a need for some improvements on these softwares like allowing the user to modify or change some techniques and incorporation of extensive meteorological and PV system components database. This study is useful for further study on degradation and performance analysis of PV power plant and a comparison of various PV simulation tools in order to identify the most suitable software.*

Keywords:*photovoltaic system, simulation tools, performance ratio, degradation*

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I. Introduction

In the recent years, Renewable energy play vital role in the production of several energies used in the world, and become one of the most significant sources of energy used for electricity generation without using fossil fuel, like gas, oil, and coal. This reduces environmental pollution and prevents global warming. Solar Photovoltaic technology is one of the most important recourses of renewable energy; hence, there is a need to develop software tools which is able to determine the potential energy output characteristics and operating performance of PV systems. This will help in comparing the performance and energy production cost of different system configurations.

Software tools related to photovoltaic hybrid systems can be classified into four categories: pre-feasibility, sizing, simulation and open architecture research tools, depends upon the purpose of the software [1]. Energy produced by a PV module depends greatly on PV materials and solar insolation. Over time, the electrical energy output will decrease, commonly due to humidity, thermal cycling, ultra-violet radiation and moisture ingress, these leads to some permanent degradation, namely corrosion, discoloration, delamination and breakage and cracking cells. Besides the internal factors, one environmental factor that significantly reduces the energy produced by a PV module temporarily is dust, though PV performance could be recovered to its maximum capacity by cleaning activities [2].EVA (Ethylene Vinyl Acetate) often degrades during long-term field operation upon exposure to UV rays present in sunlight causes discoloration, module changed color to yellow or brown, this leads to low transmissivity of light and therefore the power generated by the module is reduced. Shattering or breaking of the top glass surface can occur due to vandalism, thermal stress, handling, wind or during installation, maintenance, and transportation of modules to their installation sites [3 and 4]. Deposited dust on a PV module diminishes the illumination by absorbing and scattering sun light received by solar cells there by reducing performance of PV modules [5].The main objective of this paper is to compare various PV simulation softwares and to carry out performance analysis of 1 MW grid-connected PV power plant and to compare actual data and estimated data found from different softwares. This will provide a basic insight to a researcher to identify and utilize suitable simulation software efficiently and effectively.

A number of different simulation software has been developed to assess the performance and economical potential of photovoltaic system to simplify design process and maximize the use of the renewable energy resources. In this study 10 photovoltaic simulation softwares namely SAM, PVsyst, HOMER, PV*SOL, RETScreen, Solarius PV, HelioScope, Solar Pro, SOLARGIS, and PV F-Chart are discussed. Comparative analyses of these softwares along with their limitations, advantages, type of analysis, and availability have also been identified.

In this paper, a performance evaluation of 1 MW grid-connected PV systems installed in the north India is presented. Evaluation parameters are based on data collected between January to December 2017 and typical meteorological year (TMY) data downloaded from National Solar Radiation Data Base (NSRDB) produced by National Renewable Energy Laboratory (NREL) which is funded and monitored by the U.S. Department of Energy. Performance Ratio (PR) was calculated in order to know the efficiency and reliability of the plant.

The 1 MW grid-connected solar PV power plant in both same location and system specification was simulated using these simulation softwares, performance ratio (PR) was calculated for each software. A comparative analysis of Measured PR and Estimated PR was carried out to assess system efficiency and to know the extent to which the system deviates using these different simulation softwares.

II. Software tools for photovoltaic system

In this section, the main features of 10 simulation softwares developed for photovoltaic system design are discussed along with a comparative analysis. The study results will be then used as parts of the decision making process for the investment [6].

2.1 System Advisor Model (SAM)

The System Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry, it is freely available software developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories, USA [7]. The first public version was released in August 2007; subsequently, two new versions have been released each year, adding new technologies and financial models. Since the first public release, over 35,000 people have downloaded the software. SAM runs on both Windows and OS X with a visual C++ programming language. SAM uses weather from NREL's National Solar Radiation Database (NSRDB), SAM uses inputs like module type, inverter specifications, system design, losses, lifetime etc. to simulate system configuration and makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model. The graph and table of the SAM simulation can be exported to excel or text files. The main limitations of SAM are as follows:

- 3D shade modeling for PV systems is not supported
- No available weather data for all thelocations of the world

2.2 PhotoVoltaic systems (PVsyst)

PVsyst is a software package for the study, sizing and data analysis of complete PV systems. It deals with grid-connected, stand-alone, pumping and DC-grid PV systems, and includes extensivemeteorological and PV systems components databases, as well as general solar energy tools. This software is geared to the needs of architects, engineers, and researchers. It is also very helpful for educational training. PVsystis developed by Swiss physicist Andre Mermoud and electrical engineer Michel Villoz [8]. This software is considered a standard for PV system design and simulation worldwide, the latest version is V6 and it has 30-days evaluation mode for DEMO, unlimited version is around USD 1,021.PVsyst V6 runs under any Windows operating system and Import irradiation data from PVGIS and NASA databases. PVsyst has four (4) main features which include Preliminary Design, Project Design, Databases, and Tools. It uses inputs like plane orientation (with the possibility of tracking planes or shed mounting), system components, PV array (number of PV modules in series and parallel), inverter model, battery pack etc. to perform the simulation. Results will be generated which include several dozens of simulation variables, which may be in monthly, daily or hourly values. A report may be printed for each simulation run, including all parameters used for the simulation, and the main results. A detailed economic evaluation can be performed using real component prices, any additional costs, and investment conditions. PVsyst has some limitation as follows:

- Program screen cannot be maximized therefore can be tedious to see all parameters if using a small monitor.
- Inability to handle detailed shadow analysis

- No single line diagram

2.3 Hybrid Optimization Model for Electric Renewables (HOMER)

Homer is micro-grid optimization software developed by NREL (National Renewable Energy Laboratory), USA [9] and later enhanced and distributed by Homer Energy that comes with Simulation, Optimization, and Sensitivity Analysis tools. It is the global standard for optimization of micro-grid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. HOMER uses inputs like location, resources, loads, system components, components cost etc. to run the simulation. This software application is used to design and evaluate technically and financially the options for off-grid and on-grid power systems for remote, stand-alone and distributed generation applications. It allows the user to consider a large number of technology options to account for energy resource availability and other variables. HOMER simulates the operation of a system by making energy balance calculations in each time step (interval) of the year and compares the electric and thermal demand in that time step to the energy that the system can supply in that time step, and calculates the flow of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides on each time step how to operate the generators and whether to charge or discharge the batteries. This tool can perform energy balance calculations for each system configuration. It then determines whether a configuration is feasible, (i.e., whether it can meet the electric demand under the specified conditions), and estimates the cost of installing and operating the system over the lifetime of the project. The new HOMER Optimizer uses a proprietary derivative-free algorithm to search for the least-costly system and then displays a list of configurations, sorted by net present cost (sometimes called life-cycle cost), that user can use to compare system design options. HOMER also displays simulation results in a wide variety of tables and graphs that help user compare configurations and evaluate them on their economic and technical merits. Tables and graphs can be exported for reports and presentations. HOMER Pro runs on all Windows Operating Systems that are currently supported by Microsoft. The latest version of Homer Pro is Version 3.11.5 and was released on March 23, 2018; with a purchase option of around 160 USD per month depends upon the type of package. The 21-day free trial version is available. The limitations of HOMER are as follows:

- Inability to guest missing values or sizes
- Sophisticated and time-consuming
- Detailed input data is needed

2.4 PV*SOL premium

PV*SOL premium is German software developed by Valentine Software [10] for dynamic simulation program with 3D visualization and detailed shading analysis of photovoltaic systems. PV system designers, engineers, consultants, and installers can use the software to professionally design PV systems. PV*SOL make accurate predictions easy, give customers the best return on their investment by visualizing systems and creating professional reports. PV*SOL runs under Windows Vista, Windows 7, Windows 8 and Windows 10 with Monitor Resolution of at least 1024 x 768 pixel. This software has 3D Design for3D visualization of buildings and shading objects, rotate land area with objects, Drag-and-drop shading objects, animated sun-path, Shade frequency distribution, detailed shade analysis for each individual module. The user can also select Number of covered areas, Number of PV-Module, Number of inverters, PV Generator output, Orientation, Azimuth, Inclination, and Installation Type. The model can perform economic and performance analysis with a comprehensive report which can be exported to excel. The latest version is PV*SOL Premium 2018 was released on 23rd March 2018, and password is needed to install the trial version. The limitations are as follows:

- Sensitivity analysis is not included
- Error in the presentation of a circuit diagram
- An advanced calculation is not supported

2.5 Renewable Energy Technologies Screen (RETScreen)

RETScreen Expert is a comprehensive Clean Energy Management Software platform which enables professionals and decision-makers to identify and assess the viability of potential energy efficiency, renewable energy, and cogeneration projects; and to measure and verify the actual and ongoing energy performance of buildings, factories and power plants around the world. The software is developed by the Government of Canada in collaboration with notable international partners [11] and is used by over 525,000 people in every country and territory of the world. RETScreen is also used as a teaching and research tool by well-over 900 universities and colleges worldwide and is frequently cited in the academic literature.The first version of RETScreen was released on April 30, 1998. This model integrates a number of databases to assist the user, including a global database of climatic conditions obtained from 6,700 ground-based stations and NASA satellite data; it can also integrate benchmark database, cost database, project database, hydrology database and product database.

RETScreen Expert has analysis capabilities covering an entire project life cycle which allows the user to establish reference climate conditions at a facility site for any location on earth and compare the energy performance of various types of reference (benchmark) facilities with the estimated (modeled) or measured (actual) annual energy consumption of a facility. This software can perform feasibility and performance analysis including energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis [12].

RETScreen Expert latest version wasreleased to the public on September 19, 2016, and is available for download completely free-of-charge in Viewer mode. The full functionality of RETScreen Expert (including the ability to save, print and export files) is available in Professional mode by purchasing a renewable 12-month subscription, currently priced at CAD 869 per subscribing. The older version of the software, RETScreen Suite, is made available free-of-charge upon request. Some of the limitations are as follows:

- Inability to save, print and export files when using free view mode version.
- Data sharing problem.
- No option for time series data files Import
- Does not support more advanced calculations.

2.6 Solarius PV

Solarius PV is the professional Solar PV calculator software developed by Italian company ACCA software [13] for designing photovoltaic systems with great ease to achieve the best economic and technical solution. This model uses input like weather data, modules, inverters, batteries etc. to get technical and financial analysis for system configuration. Solarius PV can calculate the PV system's overall performance (total annual production with an hourly production rate schedule) and assess the profitability and amortization period of the entire photovoltaic system. This software allows checking the effects of shading projected onto the PV modules by nearby obstacles such as antennas and chimneys and graphically view shadow interferences. Solarius PV runs under Windows 7, Windows 8, Windows 8.1 or Windows 10 with minimum 512 MB of memory. The latest version is Solaris PV v.14.00c and was on released 13th July 2016, a password is needed to install one-month free trial version. Some of the limitations of this software are as follows:

- It is less user-friendly compared to other software.
- Advanced feasibility analysis is not supported.
- Internet connection is required for installation.

2.7 HelioScope

HelioScope is a new program introduced by Folsom Lab USA [14] for designing photovoltaic system; it has some features of PVSyst and adds the design functionality of AutoCAD, allowing designers to do a complete design with one package. Location's address, array configuration, PV module and inverter specification are the main inputs required by HelioScope. This software allows the user to estimate energy production that accounts for losses due to weather and climate. Shading, wiring, component efficiencies, panel mismatches, and aging can also be analyzed in order to provide recommendations for equipment and array layout. This tools displayed annual production, weather data set, performance ratio and other system parameters for simulation results. HelioScope is a web-based tool, so there's no software to download and you can use it from any connected computer. Instead of buying the program, you can pay a monthly or annual fee. You need to register with a helioScope account for 30-day trial version. HelioScope has limitations as follows:

- Does not support financial analysis
- Does not support feasibility analysis
- advance scientific calculation is not supported

2.8 Solar Pro

Solar Pro is robust PV design and energy simulation software developed by Japanese company Laplace Systems [15] along with integrated 3D-CAD, advanced 3D shading analysis & animations, and accurate solar electricity generation calculations. This software is used to create 3D models of residential, commercial flat-roof, ground-mounted, and single and dual-axis tracker PV systems. It allows users to visualize shading and configure module coverage easily and accurately. Solar pro predicts hourly electricity generation using scientific, industry-standard mathematical models. IV Curve calculations are performed at the module level and take into account irradiation and temperature data, shading, and other detailed loss factors. Customized reports can be generated to show detailed losses, IV-curve graph, power generation graph, color-coded array stringing configuration, and shading effects. The CAD model can be printed in any view, and dimensioned layouts can also be generated and exported. The first version of Solar Pro is released in 1997, the latest version of Solar Pro is 4.5, a password is required to install 30-day trial version. Solar pro has limitations as follows:

- It is sophisticated software as compared to others.

- It does not support an advanced feasibility study.

2.9 SOLARGIS pvPlanner

In 2010 solargis developed PV system simulation software named pvPlanner [16]. SOLARGIS pvPlanner is a map-supported online simulation tool for planning and optimization of photovoltaic systems using high-performance algorithms and climate and geographic data at high temporal and spatial resolution. This application is designed for site prospection and comparing energy yield from various PV technology options and mounting systems through simple and quick simulations. In solargis screen [17], the user can search the desired location, select PV system configuration which includes system capacity, module type, inverter specifications, mounting system, azimuth and inclination angle etc. to run the simulations. These models read the input data from 19 geostationary satellites at five principal positions, and from atmospheric and meteorological models operated by ECMWF and NOAA meteorological data centers. The main outputs of simulation process are long-term monthly and yearly values PV Electricity yield (PVOUT), Performance Ratio (PR) values, Global Horizontal Irradiation (GHI), Global in-plane or tilted irradiation (GTI), Diffuse Horizontal Irradiation (DIF), Reflected Irradiation (RI) and Temperature (TEMP). Reports and data in PDF, CSV or XLS format are downloadable. The application can be accessed at http://solargis.info/pvplanner/ only need to create an account by providing an email address and set a password. The latest version of this application is solargis model v2.1.18 and was released on 26 Feb 2018. This PV planner has limitations as follows:

- Not suitable for financial analysis
- Less technical parameters, as such feasibility analysis is not possible
- The Internet is needed to run the simulation.

2.10 PV F-Chart

PV F-chartis a comprehensive photovoltaic system analysis and design program developed University of Wisconsin, USA [18]. The program provides monthly-average performance estimates for each hour of the day of utility interface systems, stand-alone photovoltaic systems, battery storage systems and system with no interface or battery storage. This tool requires weather data, load, inverter and module configuration and financial details of the whole system. PV F-chart displays energy production and saving, system performance, and financial viability. This software runs on all version Windows. The latest version of PV F-chart is version 3.56W and it cost 400USD and 600USD for student and academic respectively, DEMO version is available free of charge. PV F-chart has limitations as follows:

- Graphs and tables can be generated but cannot be exported
- Not suitable for shading analysis
- An advanced calculation is not supported

Table 1: Main features of various software tools for photovoltaic systems

Software	Developed by	Type of Analysis	Advantages	Disadvantages	Latest Version	Availability
SAM	National Renewable Energy Laboratory (NREL), USA. 2007	Performance analysis; Economic analysis	user friendly; easy to understand; graphical representation of results; Manually add custom modules and inverters	3D shade modeling is not supported; No available weather data for other locations of the world	SAM version 2017	Free at https://sam.nrel.gov/
PVsyst	Institute of Environmental Sciences (ISE), University of Geneva, Switzerland	Performance analysis; Financial estimation used for both grid-connected, stand-alone, pumping and DC-grid PV systems,	Extensive meteorological and PV systems components databases; Has ability to identify the weaknesses of the system design through Loss Diagram; Results include several dozens of simulation variables	Program screen cannot be maximized to enable user to see all parameters if using a small monitor; Inability to handle shadow analysis; No single line diagram	PVsyst version 6.70 released on 29th March, 2018	priced, 30-day trial version is free at http://www.pvsyst.com/en/

HOMER	National Renewable Energy Laboratory (NREL), USA	Optimization and Sensitivity analysis; Technical analysis; Financial analysis	Determines the possible combinations of a list of different technologies and its size; Very detailed results for analysis and evaluation; Has optimization algorithms used for feasibility and economic analysis	Inability to guest missing values or size; Sophisticated and time consuming; Detailed input data is needed	Version 3.11.5 released on March 23, 2018	priced, 21-day free trial is available at https://www.homerenergy.com
PV*SOL	Valentine Energy Software, Germany	Shading analysis and 3D visualization; Performance analysis; Economic analysis	Vast meteorological database with over 8000 climatic location worldwide; Strong module and inverter database with over 13000 modules and 3100 inverters; Manually add custom modules and inverters	Sensitivity analysis is not supported; Complexity in building and site modeling; Error in the presentation of circuit diagram; Advanced scientific calculation is not supported	PV*SOL Premium 2018 released 23rd march, 2018	priced, 30-day trial version is free at https://www.valentin-software.com/en/products/photovoltaics/57/pvsol-premium
RETScreen	Natural Resources Canada	Benchmark analysis; Feasibility analysis; Performance analysis; Portfolio analysis	Strong meteorological and product database; Contains extensive integrated training material; High strength in financial analysis	Inability to save, print and export files when using free view mode version; Data sharing problem; No option for time series data files Import; Does not support advanced calculations.	RETScreen Expert released on September 19, 2016.	priced, Viewer mode is available free-of-charge at http://www.nrcan.gc.ca/energy/software-tools/7465
Solarius PV	ACCA software, Italy	Technical analysis; Economic analysis; Shading analysis	Extensive meteorological database; Numerical and graphical results can be easily exported; Has photographic simulation feature	Less user-friendly as compared to other softwares Advanced feasibility analysis is not supported; Internet connection is required for installation	Solaris PV v.14.00c released on 13rd July, 2016	priced, 30-day free trial version is available at http://www.accasoftware.com/en/solar-pv-system-design-software/
HelioScope	Folsom Lab, San Francisco, USA	Technical analysis; shading analysis	User-friendly; Is a web-based tool, so there is no software to download; Provides a detailed wiring diagram; Has 3D model design	Does not support financial analysis; Does not support feasibility analysis; Does not support advance scientific calculation	updated in 2017	30-day trial version is available at https://www.helioscope.com/
Solar Pro	Laplace Systems Company, Japan	Technical analysis; shading analysis; Economic analysis; Performance modeling	Strong meteorological database; Advanced 3D shading analyses; Provides system layouts; Provides detailed and customized reports which can be exported	Sophisticated software as compared to other softwares; Advanced feasibility study is not supported	Solar Pro 4.5	Priced, 30-day trial is available https://www.lapsys.co.jp/english/products/where_to_buy/index.html

SOLARGIS	Solargis, Slovakia. 2010	Technical analysis; Planning and optimization	User-friendly; is a web-based tool, so there is no software to download; Provides a detailed output with graphs and tables	Not suitable for financial analysis; Less technical parameters; Feasibility analysis is not supported; Internet is needed to run the simulation.	Solargis model v2.1.18 released on 26 Feb 2018	30-day trial version is available at https://solargis.info/pvplanner
PV F-Chart	University of Wisconsin, USA	Technical analysis; Financial analysis	User-friendly; Provide detailed graphical and numerical output; Weather data can be added manually	Not suitable for shading analysis; Advanced calculation is not supported; Graphical and numerical output; Graphs and tables can be generated but cannot be exported	PV F-chart is version 3.56W	DEMO version is available free of charge at http://www.fchart.com/pvfchart/

III. Setup and Description of the Grid-Connected PV system

A grid-connected PV system consists of solar panels, inverters, a power conditioning unit and grid connection equipment. It has effective utilization of power that is generated from solar energy as there are no energy storage losses. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load to the utility grid. But, in standalone systems batteries are used to store energy or else energy has to be directly connected to load [19].

3.1 Geographical location of the site

The I MW solar power plant installed at Sharda University, Uttar Pradesh, India is located at latitude 28.4744° N and longitude 77.5040° E of 202m height, the meteorological data were collected from NSRDB. The Plant as it located at good geographical location where it can absorb more solar radiation in order to generate power effectively.

3.2 Plant layout

The 1 MWp PV solar system has 3228 solar modules with a total area of 6197.6 m^2. 18 modules are connected in series to make 178 strings. The plant area is divided into 12 different blocks; each individual block has the generating capacity of about 100 kW thus total of 12 blocks combined to form a 1 MW generation capacity (see Fig. 1). The modules SS320P (each of 310 Wp capacity) having 72 solar cells made up of polycrystalline silicon having 16.15% efficiency are used in the entire PV system. The modules are free from any of shading effect and are fixed with tilt angle of 28° (equal to the latitude of the corresponding location to get maximum solar radiation) facing south at an azimuth angle of 0°. The PV systems are mounted on metal frames by concrete pillars. The modules were cleaned with water at an interval of 15 days in order to reduce the soiling loss [20]. A 3-phase 50KW inverter was used to convert DC to AC which was then fed directly into the state grid. 21 inverters were used for the entire system. The inverter has a rated efficiency of 98.3%. The PV module and inverter specifications are given in Table 2.

Table 2: PV module and inverter specifications

PV module	Specification	Inverter	specification
Module type	Polycrystalline	Inverter capacity	50kW
Operating voltage	1000V	Input side (DC)	1000V
I_{mp}	8.52A	Maximum voltage	$610V_{dc}$
V_{mp}	36.40V	Rated voltage	51200W
P_{max}	310W	Rated power	$480\text{-}800V_{dc}$
I_{sc}	8.92A	Voltage range	110A
V_{oc}	44.71V	Maximum current	
β	-0.34%	Output side (AC)	3-phase
α	0.05%	Rated AC power	50000W
γ	-0.43%	AC voltage range	320-480V
NOCT	-45^0C to $+85^0C$	Output current	77A
Module area	$1.92m^2$	Output frequency	50Hz / 60Hz
Module weight	22.1kg	Efficiency	98.30%
Efficiency	16.15%	Weight	95kg

Fig. 1: View of 1 MWp rooftop grid-connected solar PV system.

IV. Methodology for performance analysis of the PV system

In this paper, performance of grid-connected PV solar power plant is categorized into three stages.

1. Tilted radiation was calculated manually using typical metrological year (TMY) data, and then Performance ratio was calculated.
2. Performance ratio of PV solar power plant was calculated using all 10 simulation softwares studied in this paper
3. Performance ratio of measured data was compared with the entire 10 softwares simulated performance ratio.

4.1 Tilted Radiation

The amount of insolation acquired by the module during a certain time interval is one of the main preconditions for designing a PV system. It can be estimated by calculating the position of the Sun in the sky as well as the Air Mass value. Although this type of calculations gives a feeling of how much irradiation is available for a particular location and module orientation and how it is varying throughout the year, its output can't be used for the real system design because it doesn't include local weather variation which can dramatically change the radiation intensity. Another way of doing this is to use empirical radiation data collected by meteo station located at the place of interest. In TMY file one can find both beam and diffuse components of radiation. Beam irradiance implies that it is received by the surface perpendicular to the Sun's rays. The beam component is actually calculated from diffuse and global horizontal irradiances, which are directly measured. For the systems with 2-axis trackers, adjusting themselves to face the sun in the same fashion as sunflowers do, the beam component comes directly from TMY (where it is called Direct Normal Irradiance, DNI). Unfortunately, the vast majority of PV systems are fixed in place and don't rotate. So they receive only a portion of direct sunlight which can be calculated having in mind the system location, module tilt and orientation [21].

The total amount of radiation received by the PV module, G, is composed of direct (beam), B, and diffuse, D, components.

$$G = B + D \tag{1}$$

Beam component is given by:

$$B = DNI(sin(\delta)\, sin(\varphi)\, cos(\beta) - sin(\delta)\, cos(\varphi)\, sin(\beta)\, cos(\psi) + cos(\delta)\, cos(\varphi)\, cos(\beta)\, cos(HRA) + cos\delta sin\varphi sin\beta cos\psi cosHRA + cos\delta sin\psi sinHRA sin\beta \tag{2}$$

Diffuse component is given by:

$$D = DHI\left(\frac{180-\beta}{180}\right) \tag{3}$$

Where

DNI is Direct Normal Irradiance

DHI is Diffuse Horizontal Irradiation

δ is the Declination Angle,

φ is the latitude of the location,

β is module tilt,

ψ is module azimuth (orientation measured from South to West),

and HRA is hour angle

Declination angle

The declination angle, denoted by δ, varies seasonally due to the tilt of the Earth on its axis of rotation and the rotation of the Earth around the sun. If the Earth were not tilted on its axis of rotation, the declination would always be 0°. However, the Earth is tilted by 23.45° and the declination angle varies plus or minus this amount. Only at the spring and fall equinoxes is the declination angle equal to 0°. In this paper the declination angle was taken as 0^0.

$$\delta = -23.45^0 \times cos\left(\frac{360}{365} \times (d + 10)\right) \qquad (4)$$

Where
d is the day of the year with Jan 1 as d = 1

Hour Angle (HRA)

The Hour Angle converts the local solar time (LST) into the number of degrees which the sun moves across the sky. By definition, the Hour Angle is 0° at solar noon. Since the Earth rotates 15° per hour, each hour away from solar noon corresponds to an angular motion of the sun in the sky of 15°. In the morning the hour angle is negative, in the afternoon the hour angle is positive. In this paper Indian local time was used, which is 5.5.

$$HRA = 15^0(LST - 12) \qquad (5)$$

$$LST = LT + \frac{TC}{60}$$

$$TC = 4(Longitude - LSTM) + E_0T$$

$$LSTM = 15^0 \Delta T_{GMT}$$

$$E_0T = 9.87\, sin(2B) - 7.53\, cos(B) - 1.5 sin(B)$$

$$B = \frac{360}{365}(d - 81)$$

Where
LST is local solar time
LT is local time
TC is time correction factor
LSTM is local standard time meridian
EoT is equation of time
ΔT_{GMT} is the difference of the local time (LT) from Greenwich Mean Time (GMT) in hours. 15°= 360°/24 hours.
B in degrees and d is the number of days since the start of the year

Performance parameters are developed by International Energy Agency (IEA) [22] for analyzing the performance of solar PV system. In this paper, some of the performance parameters are discussed

Array Yield

The array yield is defined as the ratio of energy output from a PV array over a particular period (day, month or year) to its rated power and is given by

$$Y_a = \frac{E_{DC}}{P_{PV\ rated}}$$

Final Yield

The final yield is defined as the ratio of net daily, monthly or annual AC energy output of the entire PV system which was supplied by the array to the rated power of the installed PV array.
The daily final yield is given by

$$Y_{fd} = \frac{E_{AC.d}}{P_{PV\ rated}}$$

Reference Yield

The reference yield Yr is defined as the total daily in plane solar irradiation Ht (kWh/m2) divided by the reference irradiation Gi-ref (1 kW/m^2). It is given by

$$Y_r = \frac{H_t}{G_{i.\ ref}}$$

Capacity Utilization Factor

The capacity utilization factor (CUF) is defined as the ratio of actual annual energy generated by the PV system (EAC.a) to the amount of energy the PV system would generate if it is operated at full rated power for 24 h per day for a year.

$$CUF = \frac{E_{AC.a}}{P_{PV\ rated} \times 24 \times 365} \times 100$$

PV module efficiency

PV module efficiency is given by

$$\eta_{PV} = \left(\frac{P_{DC}}{G_t \times A_m}\right) \times 100$$

Where

Gt is Total in-plane solar irradiance, W/m2

Am is PV module area, m2

Inverter efficiency

The instantaneous inverter efficiency is given by

$$\eta_{inv} = \frac{P_{AC}}{P_{DC}}$$

System efficiency

The instantaneous PV system efficiency is given by

$$\eta_{sys} = \eta_{PV} \times \eta_{inv}$$

Performance Ratio

The performance ratio is the ratio of the actual and theoretically possible energy outputs. It is largely independent of the orientation of a PV plant and the incident solar irradiation on the PV plant; it is also defined as the ratio of the PV system efficiency to its efficiency at STC and is given by

$$\mathrm{PR} = \frac{\mathrm{Y_f}}{\mathrm{Y_r}}$$

The final yield of the system (Yf) is defined as the ratio of the final or actual energy output of the system to its nominal D.C power. The Yf normalizes the energy produced with respect to the system size [22].

$$\mathrm{Y_f} = \frac{\text{final energy output (kWh)}}{\text{norminal DC power (kW)}}$$

The reference yield (Yr) is the ratio between total in-plane irradiance to that of the PV's reference irradiance. The PV reference irradiance at STC condition is equal to 1000W/m2. The reference yield is also called the Peak Sunshine Hours [23].

$$\mathrm{Y_r} = \frac{\text{total inplane irradiance (kWh/m}^2\text{)}}{\text{PV reference irradiance (kW/m}^2\text{)}}$$

Degradation Rate (R_D)

Degradation is the gradual deterioration of the characteristics of a component or of a system which may affect its ability to operate within the limits of acceptability criteria and which is caused by the operating conditions [24]. Degradation Rate (R_D) can be calculated as:

$$\mathrm{R_D} = \frac{\text{initial PR} - \text{final PR}}{\text{initial PR}}$$

Visual Degradation observed in field

All the 3228 modules underwent visual inspection using NREL visual inspection Checklist [25]. Photographs were taken for the various modules defects found in the plant. The effects of dust accumulation on a PV module's surface were also analyzed.

4.2 Simulation using different softwares

The 1 MW grid-connected solar PV power plant was simulated using these softwares; SAM, PVsyst, HOMER, PV*SOL, RETScreen, Solarius PV, HelioScope, Solar Pro, SOLARGIS, and PV F-Chart. Performance ratio was calculated for different softwares for comparative analysis in selecting suitable softwares.

V. Results and Discussion

5.1 PV Energy Generation

The monthly average solar radiation on the tilted PV array indicates that the solar radiation is minimum during December (88.3459 kW/m2/d) and maximum in May (157.8408 kW/m2/d), this is due to temperature variation of the location. The monthly PV power generated is illustrated in the figure 2. As the temperature increases the power output decreases up to some extent even if there is good amount of radiation. Also, with increase in temperature, the power generation decreases slightly even when there is constant solar irradiance.

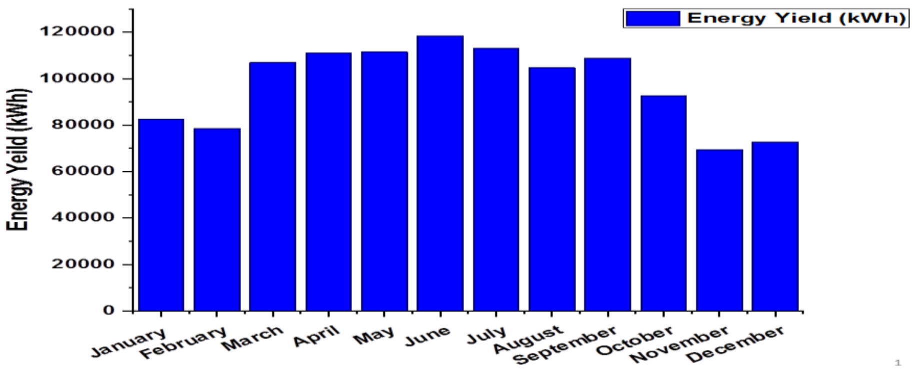

Fig. 2: annual energy yield

5.2 Performance Ratio (PR)

The performance of the PV system was analyzed through Performance Ratio (PR). According to SMA [26], performance ratio shows the proportion of the energy that is actually available for export to the grid after deduction of energy loss (e.g. due to thermal losses and conduction losses) and energy consumption for operation. In winter season, the highest PR of 82.31% was observed during December 2017. The average PR during winter season was found to be 76.18%. The PR varies from 0.73 to 0.82 during winter and the lowest PR of 0.73 obtained during November due to lowest final yield. In summer season, the average PR was found to be 75.73% which is lower than that of winter. The higher PR during summer is mainly due to the higher final yield. In Rainy season, the average PR during this season was found to be 80.13%. Comparatively, higher PR during this season may be due to module and inverter efficiency during this season. The higher PR of 87.53% observed during June 2017 and this may be due to higher final yield of 118380 kWh/d during this month. The performance ratio is illustrated in the figure 3.

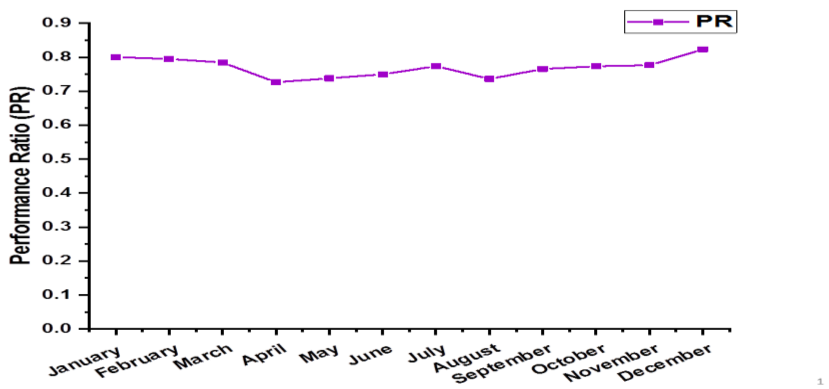

Figure 3: Average performance ratio for various months.

5.3 capacity Utilization factor (CUF)

The annual monthly average CUF of the PV system was found to be 14.75 and is within the range of some of the previous studies conducted in India. The CUF varies from 12.85% to 16.85%. However, the highest

CUF (16.85%) is observed in both month of March and April due to highest energy production while the lowest CUF (12.85% and 12.88) is observed in December and July respectively due to lowest energy generation. The variation in the CUF is due to change in climatic conditions. CUF is illustrated in Fig. 4.

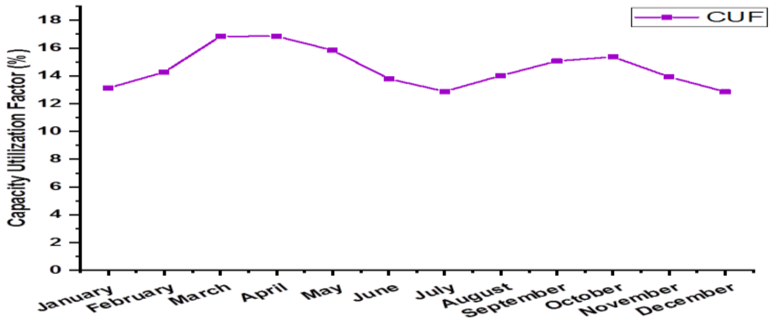

Figure 4: capacity Utilization factor for various months.

5.4 Degradation Analysis and Defects of the plant

Analysis of module degradation shows that modules discoloration and glass shattering are form of degradation found in the field (see Fig. 5 and Fig. 6). Beside these defects, dust accumulations have been seen in most of the modules (see Fig. 7). Module discoloration is due to present of ultra-violet radiation at high temperature, it has found in 14 modules. Glass shattering occurred due to improper handling during transportation, installation and maintenance, and is found in 5 modules only. However, dust accumulation is due to environmental factor (composite climate), though performance can be recovered by regular cleaning of the modules. The annual degradation rate was found to be 0.98%/year.

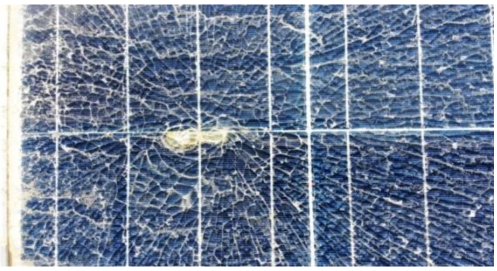

Fig. 5:Module with broken glass

Fig. 6:Module with a discoloration

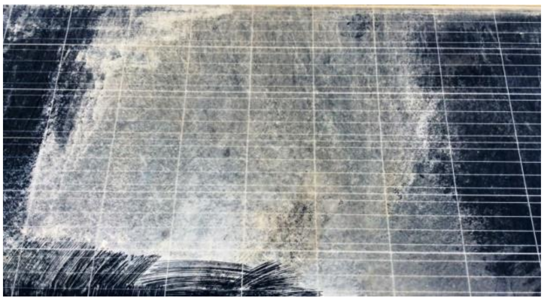

Fig. 7: Module with accumulation of dust

5.5 Simulation using different softwares and performance comparison

Performance ratio was calculated from the simulated data obtained from different softwares. The annual average performance ratio obtained from actual measured data was found to be **0.7737.** The results obtained from the measured data is compared with SAM, PVsyst, HOMER, PV*SOL, RETScreen, Solarius PV, HelioScope, Solar Pro, SOLARGIS, and PV F-Chart. The results are presented in Table 3. The actual performance closely matches with the simulated performance of different softwares over the entireyear. Homer, Solarius PV, SOLARGIS, SAM and PV F-Chart has annual performance ratio of 0.7897, 0.7798, 0.7602, 0.7576 and 0.7854 respectively and is almost similar with the actual performance ratio of the solar power plant. From PVsyst, PV*SOL, and RETScreen, Solar Pro results, the performance ratio obtained has less difference with the actual performance ratio. Only HelioScope has completely deviated from actual performance ratio of the solar power plant with performance ratio of 0.6517. (see Fig. 8 and Fig. 9).

Table 3: annual average performance ratio for all 10 softwares

S/N	softwares	Avg. PR
1	SAM	**0.7576**
2	PVsyst	0.7990
3	Homer	**0.7897**
4	PV*SOL	0.8053
5	RETScreen	0.8236
6	Solarius PV	**0.7798**
7	HelioScope	0.6517
8	Solar Pro	0.7097
9	SOLARGIS	**0.7602**
10	PV F-Chart	**0.7854**

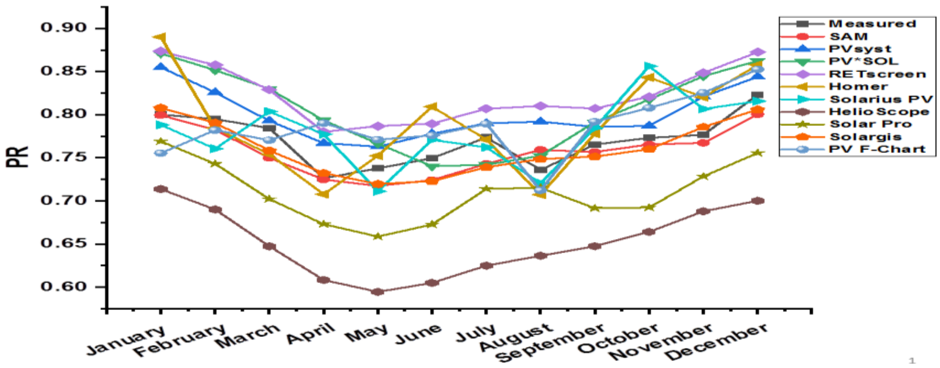

Fig. 8: monthly average performance ratio for all 10 softwares.

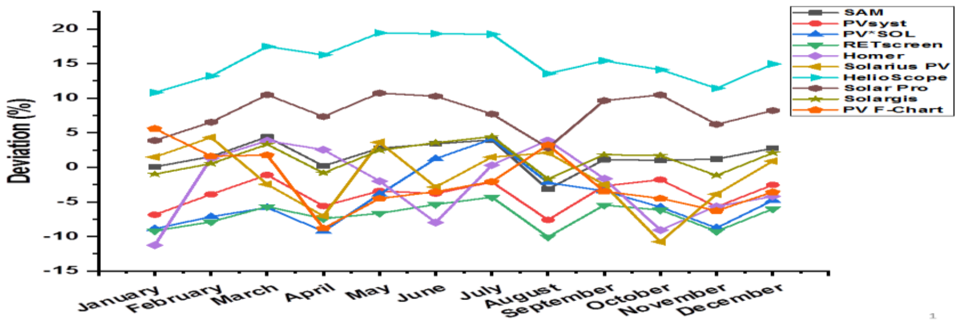

Fig. 9: Performance ratio deviation from actual performance ratio

VI. Conclusion

A review of 10 simulation softwares used for photovoltaic systemalong with comparison study are presented in this paper.Degradation and performance analysis of I MW grid-connected PV solar power plant was carried. These simulation tools were used to ascertain performance of the plant, the simulation results are then compared with the actual performance of the PV plant. The conclusions are as follows:

- The main modes of module degradation found in the plant arediscoloration and glass shattering, discoloration is due to present of ultra-violet radiation at high temperature while glass shattering occurred due to improper handling during transportation, installation and maintenance. However, beside these defects, dust accumulations have been seen in most of the modules, and are due to environmental factor, though it can be overcome by regular cleaning of the modules.
- Annual average performance ratio and capacity utilization factor are found to be 0.7737 and 14.57% respectively, which is within the range of studies conducted in other countries. Annual degradation rate is determine based on performance ratio of the plant and is found to be 0.98%/year.

- Out of the 10 simulation softwares, Homer, SAM and PVsyst are found to be the most widely used and most effective tools because of their ability to carry out multiple analyses which makes it easier and faster to evaluate different system configurations.
- Approximately all these simulation softwares has complete general modeling, user-friendly interface and have undergone a reasonable experimental validation. The present status of all the softwares is known and is reported in this paper. However, Homer, PVsyst, PV*SOL, SOLARGIS AND SAM are softwares recently updated in 2018.
- All 10 softwares have various limitations for solving certain problems, with few having minor limitations. There is need for some improvements on these softwares, like allowing user to modify or change some techniques, more user-friendly, incorporation of more weather data for other location in the world, and more advanced technical and economic analyses.
- Homer, Solarius PV, SOLARGIS, SAM and PV F-Chart are found to be the best and suitable software for performance analysis in this location because of closeness of their performance ratio to that of actual performance ratio.
- The performance analysis carried out on 1 MW solar power plant was evaluated on annual basis. The annual performance ratio was found to be 0.7737 which is within the range of studies conducted in other countries.
- Base on the overall performance of I MW installed roof-top solar PV power plant, it shows that solar PV power is feasible solution for power supply and reduces large number of tones of CO_2 from atmosphere.

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