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RESULTS IN PERFORMANCE IMPROVEMENT AND OPERATIONAL OPTIMIZATION OF PHOTOVOLTAIC COMPONENTS AND SYSTEMS

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Abstract. *New trends in advanced solar cells technologies regarding the conversion efficiency increasing and cost drop are analysed. In order to overcome the conversion efficiency Shockley-Queisser limitations new types of solar cells were developed (based on the third and fourth generations). A global vision in modeling and simulation of advanced solar cells was considered.*

High opportunities in PV modules and systems are based on new adhesive solutions for PV modules, development of PV ribbon products and spectral corrections for PV performance modelling, reliable solar radiation database and progressive integration of PV systems in electricity market.

Modelling and simulation of photovoltaic systems represent an essential task for their integration in current power applications. A comprehensive analysis of the most interesting software packages used for simulation of a Photovoltaic Park is achieved and commented for future development.

Keywords: Trends, challenges, opportunities, advanced solar cells, modelling and simulation, PV system, PV Park, simulation, modelling, software tools.

1. Introduction

The speed and scale of the current development of the photovoltaic (PV) industry in the last 30 years is extremely surprising and remarkable [1, 2]. It was accompanied by the rapid dropping of the PV prices. The PV revolution has reflected the microelectronic revolution in several ways. One of its attractive features is represented by the international contributions in PV industry and technology. There is a fantastic leap between the first PV laboratories in fundamental physics and chemistry from Europe, since 60 years ago and the modern industrial PV laboratories and manufacturing all over the world (Europe, USA, Japan, China etc.). To understand how it was possible to reach this impressive level of development, it would be necessary to consider the talent of the researchers who succeeded to introduce lower cost abundant PV materials, new methods of photon management, and new paradigms in PV conversion [3].

In the recent years, the share of the energy produced from renewable energy sources has grown considerably. This kind of energy presents numerous advantages, which lead to the sustainable development of society, but it has a major drawback: it is very fluctuant. This drawback becomes more and more an

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issue, since the increase in the percentage of total energy production using renewable energy sources could have a negative impact on energy distribution equipment, as well as on the quality of energy.

In the case generated by photovoltaic systems based on small or large photovoltaic power plants, energy quality varies not only in annual cycles (different angles of the incident solar radiation depending on the season), or day-night cycle, but also depends on the spontaneous factors such as clouds, nebulosity, aerosols, etc.

For these reasons, the present work proposes a comprehensive study on the most interesting software packages used for simulation and analysis of a photovoltaic system developed for energy purposes and to compare the obtained results in order to identify the most efficient way for estimations and forecasts.

2 NEW TRENDS IN PV TECHNOLOGIES

2.1 Advanced solar cells technologies

According to the World Energy Vision 2100 recommended by German Advisory Council on Global Change [1], Solar Photovoltaic electricity can become a major source of energy with approx. 20% in 2050 and 70% in 2100 (see Figure 2.1).

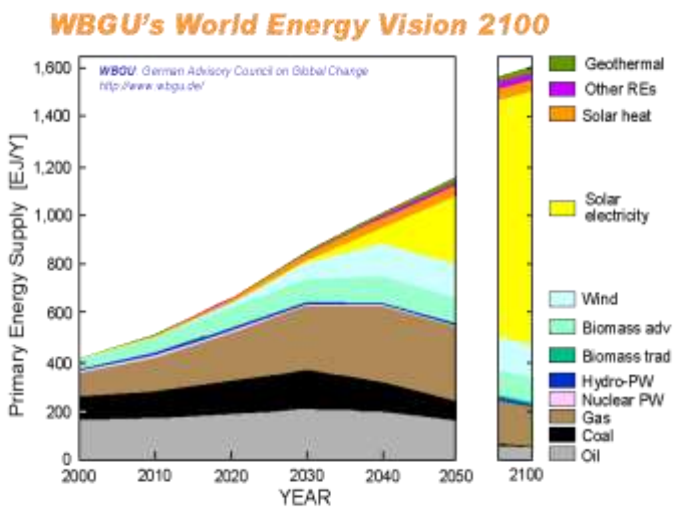


Figure 2.1 Transforming the global energy mix: Reserve of primary energy by 2050/2100 [2]

The main performances of different types of solar cells including: conversion efficiency, area, fill factor (FF) and main electric parameters (short circuit current J_{sc} and open circuit voltage V_{oc}) are presented in the Table 2.1. We could remark that compound multi-junction and concentrator solar cells together with CdTe solar cells and CIGS (CulnGaSe$_2$) solar cells are expected to have high efficiency. At the same time the development of heterojunction Si solar cells with transparent conductive oxide layers has very good perspectives.

Table 2.1. Conversion efficiency of monocrystalline Si, polycrystalline Si, CIGS, CdTe, organic dye and polymer solar cells [3]

Classification	*Efficiency (%)*	*Area(cm^2)*	*V_{oc}(V)*	*Jsc(mA /cm^2)*	*FF(%)*	*Test Centre (date)*
Si(single crystal)	25.0±0.5	4.00(da)	0.706	42.7	82.8	Sandia(3/99)
Si (multicrystal)	20.4±0.5	1.002(ap)	0.664	38.0	80.9	NREL(5/04)
a-Si	9.6±0.3	1.070(ap)	0.859	17.6	63.0	NREL(4/03)
a-Si/nc-Si/nc- Si(tandem)	12.5±0.7	0.27(da)	2.011	9.11	68.4	NREL(3/09)
a-Si/mc-Si (tandem)	11.9±0.8	1.227	1.346	12.92	68.5	NREL(8/10)
a-Si/mc-Si (tandem)	11.7±0.4	14.23(ap)	5.462	2.99	71.3	AIST(9/04)
CIGS	20.3±0.6	0.5015(ap)	0.740	35.4	77.5	FhG-ISE(6/10)
CdTe	16.7±0.5	1.032(ap)	0.845	26.1	75.5	NREL(9/01)
GaAs	27.6±0.8	0.9989(ap)	1.107	29.6	84.1	NREL(11/10)
InP	22.1±0.7	4.02(t)	0.878	29.5	85.4	NREL(4/90)
GaInP/GaInAs/Ge 3-J (con-centration)	41.6±2.5 364-suns	0.3174(da)	3.192	1.696A	88.74	NREL(8/09)
InGaP/GaAs/InGaAs 3-J (1-sun)	35.8±1.5	0.880(ap)	3.012	13.9	86.3	AIST(9/09)
Dye-sensitized	11.2±0.3	0.219(ap)	0.736	21	72.2	AIST(3/06)
Organic polymer	8.3±0.3	1.031(ap)	0.816	14.46	70.2	NREL(11/10)

(da)=designed illumination area; (ap)=aperture area; (t)=total area

The cost drop of PV modules is essential for the implementation of large scale photovoltaic systems. The comparison of PV module price for different types of solar cells is presented in the Figures 2.2, 2.3 and 2.4.

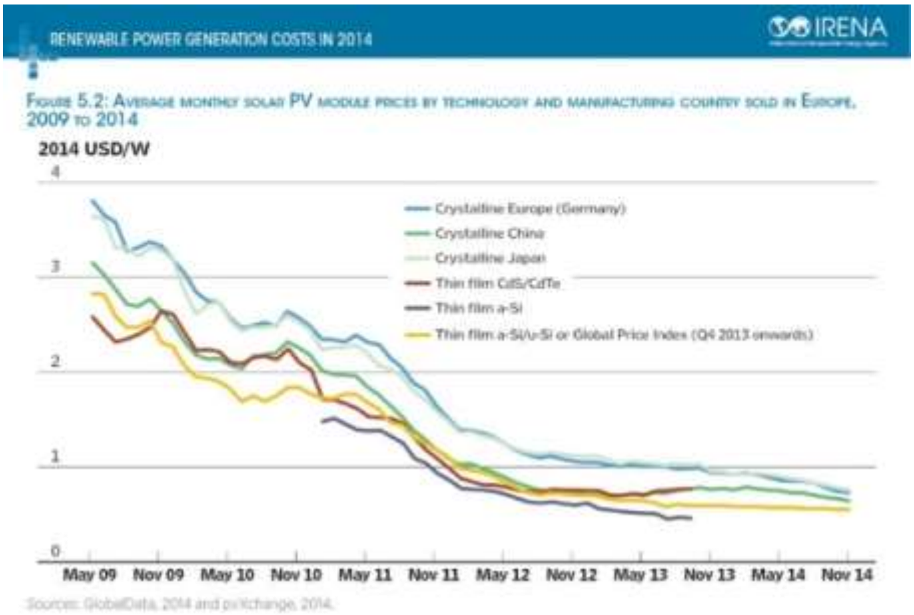
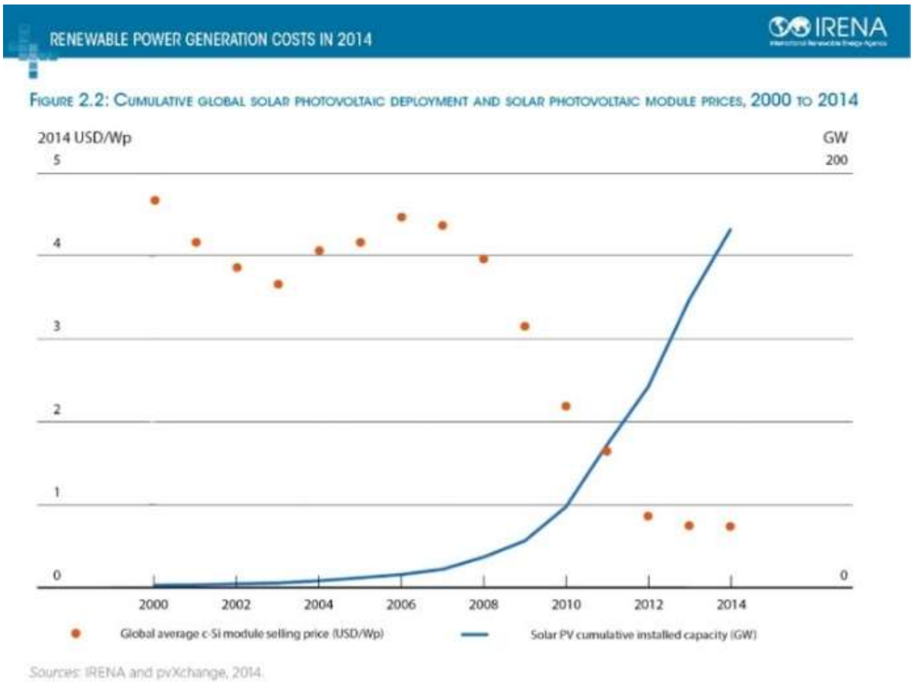


Figure 2.2 Average monthly PV module prices in Europe, 2009 to 2014 [4]



2.

Figure 2.3 Cumulative global PV development and PV module prices, 2000 to 2014 [4]

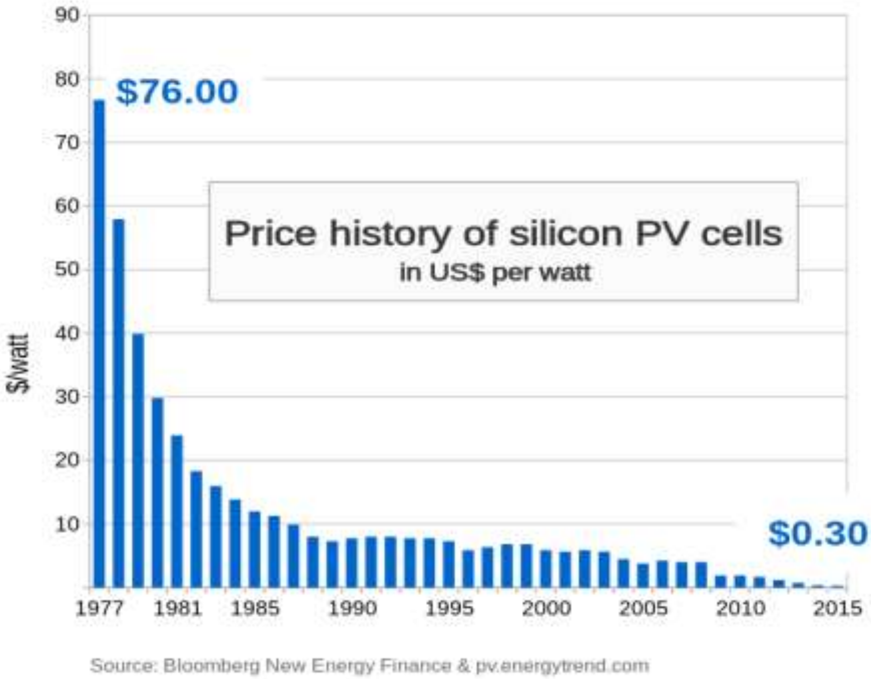


Figure 2.4. Evolution of price for silicon PV cells [5]

2.2 Modeling and simulation for advanced solar cells – a global vision

The book **"Advanced Solar Cell Materials, Technology, Modelling, and Simulation**", *Laurentiu Fara* and *Masafumi Yamaguch*i (editors), published by ***IGI Global(USA),*** 2013 [1], could be considered as a precursory contribution to the MultiscaleSolar COST project (2015–2019) and a trial to introduce a global vision in modelling and simulation of advanced solar cells. Four generations of solar cells have been developed until now. The third and fourth generations of solar cells are potentially able to overcome the Shockley-Queisser conversion efficiency of 31% at l-sun and 41% under concentration for single bandgap solar cells [6]. Limiting efficiencies are expected to be 28.9%, 23.5%, 23.5%, 17.5%, and 16% for crystalline Si, thin-film Si, CIGS as well as CdTe, dye-sensitized and organic solar cells, respectively. On the other hands, because 41.6% efficiency has been realized with concentrator InGaP/InGaAs/Ge 3-junction solar cells, concentrator 4-junction or 5-junction solar cells have great potential for realizing super high-efficiency of over 50%.

At the same time, in order to to overcome conversion efficiency limitations, developing new types of solar cells based on new materials and new concepts is very important [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21]. Third generation solar cells include both multi layered/multi-junction solar cells and intermediate bands, hot-carrier solar cells.

Realistic conversion efficiencies obtained for solar cells by using the above concepts could be less than 55% by considering possible efficiency based on the realistic multi-junction (tandem) concept. However, further R&D for new materials and new concepts is necessary to challenge to overcome the Shockley-Queisser limit.

The book is dedicated especially to the third generation of solar cells [48] and it is structured on five sections, namely:

• **Section 1: Basic Topics**: Chapter 1, "New Trends in Solar Cells," and Chapter 2, "Physical Limitations of Photovoltaic Conversion".

• **Section 2: Quantum Well Solar Cells**: Chapter 3, "Quantum Well Solar Cells: Physics, Materials, and Technology," Chapter 4, "Quantum Confinement Modelling and Simulation for QuantumWell Solar Cells," Chapter 5, "Analytical Models of Bulk and Quantum Well Solar Cells and Relevance of the Radiative Limit".

• **Section 3: Hybrid and Polymer Solar Cells**: Chapter 6, "Hybrid Solar Cells: Materials and Technology," Chapter 7, "Polymer Solar Cells," Chapter 8, "Organic Solar Cells: Modelling and Simulation".

• **Section 4: High Efficiency Solar Cells**: Chapter 9, "Super High Efficiency Multi-Junction Solar Cells and Concentrator Solar Cells," Chapter 10, "Quantum Dot Solar Cells," Chapter 11, "Intermediate Band Solar Cells: Modelling and Simulation," Chapter 12, "Phononic Engineering for the Hot Carrier Solar Cells".

• **Section 5: Luminescent Solar Concentrators: Prospects and Strategies for Advanced Solar Cells**: Chapter 13, "The Luminescent Solar Concentrator: Advances, Optimization, and Outlook, Chapter 14, "Prospects and Strategy of Development for Advanced Solar Cells". This special book looks for to present the main results obtained by international research regarding materials, technology, modelling, and simulation of different types of advanced solar cells.

There are simulated the essential mechanisms using fundamental models of advanced solar cells, in order to understand better these mechanisms and to evaluate new methodologies [21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31]. New materials, concepts and devices are considered. The book stressed on innovative approaches in photovoltaics using quantum confinement, as well as light and thermal management. Very large scale installation of PV power generating systems and further improvements in conversion efficiencies and reliability and lowering the cost of solar cells and modules are necessary.

2.3 High opportunities for PV modules and systems development

The main high opportunities for PV development are put in evidence by the international research [51] and could be considered as follows:

- *Bonding and sealing technology – new adhesive solutions for PV modules*
- *Development of PV ribbon products*
- *Reliable solar radiation database to make smart forecasted PV output*
- *PV performance modelling – spectral corrections*
- *Progressive integration of PV systems in electricity market to maintain the grid stability*

A. Bonding and sealing technology – new adhesive solutions for PV modules

Because the market conditions put pressure on the entire photovoltaic installation, efforts are being made for developing new processes for optimization and installation to reduce the costs. This also leads to new materials and methods that have to be implemented into production and installation. There are a number of features that new adhesive and sealants are currently researched to be developed, leading to lower production costs and higher efficiency. For example, Sika Corporation is adding value to their products by implementing the following benefits to their products [32]:

Table 2.2. Features and benefits in using new bonding and sealing technology [33]

	Adhesive features	Benefits for the photovoltaic system
Substrate-friendly joining method	■ Absorbs shocks and reduces vibrations ■ Optimal load distribution across the surface ■ Accomodates the different thermal expansion coefficients of the construction and glass ■ Compensates for manufacturing tolerances ■ Bonding of finished materials (e.g. aluminum – glass)	■ Eliminated stress peaks for reduced glass breakage ■ Dimished formation of micro cracks in cells ■ Higher yield over service life ■ Withstands all climatic zones ■ Simplified automation and fewer upstream process steps ■ No damage to corrosion protection as a result of drilling or screwing
Scope for design	■ Concealed bonding makes for smooth, barrier-free surfaces ■ Weight reduction	■ Elimination of frames or mechanical fixing ■ Increased self cleaning of modules for higher yield ■ Appeal for BIPV solutions ■ Lower transport costs ■ Simplified installation ■ Wider range of applications
Dynamic load capacity	■ Wind and other loads can be transferred evenly into the sub construction	■ Less glass breakage and fewer micro-cell cracks ■ Improved long-term durability ■ Reduced operating costs ■ Less maintenance work
Product performance	■ Different curing speeds and technologies available ■ Widely approved (e.g. IEC 61215/61646/61730, EOTA ETAG 002, UL 94 / 764)	■ Curing speed fits the process to eliminate curing zones ■ Moisture independent curing possible ■ Secured system durability and performance

The company is also introducing a different way to mount the photovoltaic modules by moving from frames and mechanical mounting, to a bonded frameless mounting solution that has the following advantages [32]:

Table 2.3. Key system benefits [33]

KEY SYSTEM BENEFITS

Reduced costs in production and installation	**Increased durability and performance**
■ Savings in costs of up to 15% compared to common framing and installation systems	■ Reduced glass breakage through elimination of stress peaks
■ Reduced installation time on-site of up to 40%	■ Minimized micro cracks on cells due to stress distribution imply higher yield over service life
■ Savings in backrail material of up to 15% compared to tape solutions	■ Elimination of raised edges from frames that trap dirt, snow or water which harm the laminate and reduce the power output
■ Value added through mounting integration, new designs for BIPV and architectural appeal	■ Structurally bonded with an adhesive technology which meets stringent durability requirements
■ Elimination of electrical grounding	■ Simplified tolerance compensation of bonded components
■ Minimized material handling compared to clamping	

B. Development of PV ribbon products

One of the most important components of the PV system design is represented by the PV ribbon products. Efforts are made for producing more efficient solar tabbing and bus wire to help obtain the highest efficiency possible. The latest technology developed by Ulbrich Solar Technologies, consists in a innovative grooved solar cell tabbing ribbon, that increases the efficiency of a solar module by reflecting light back onto the surface of the cell. This grooved ribbon replaces the traditional wire that connects solar cells together. Eighty percent of the photocurrent from light that strikes the ribbon is recovered-far better than the 5% recovered by standard interconnects wire. The recaptured light creates up to a 2% module efficiency gain. In addition to tinned copper wire, Ulbrich also manufactures silver plated copper, aluminium alloys, hybrid alloys and metal substrate materials [34].

C. Spectral corrections for PV performance modelling

Solar spectral irradiance variation has a demonstrated effect on photovoltaic device performance**.** The significance of the effect with respect to energy yield has been shown to be technology-specific, through device spectral response, and site-specific, since spectral variation depends on atmospheric path length and cloud cover. These factors cause diurnal, seasonal, and geographic variations in spectral distribution that can increase or decrease I_{sc}. Variations in spectral distribution are more likely to impact the performance of PV modules that respond to a narrower wavelength range of solar radiation, such as amorphous silicon, than those that respond to a wider wavelength range of solar radiation, such as crystalline silicon [35].

Various approaches for correcting variations in spectral distribution have been completed. Some of the most important are (1) empirical relationships based on air mass or path length through the atmosphere, and (2) use of spectral irradiance models with PV module spectral response data [36].

D. Reliable solar radiation database to make smart forecasted PV output

Sandia National Laboratories is facilitating a collaborative group of PV professionals (PV Performance Modelling Collaborative or PVPMC) [37]. This group is interested in improving the accuracy and technical rigor of PV performance models and analyses. Solar radiation databases and important weather data that could influence the PV forecasted output could be found in some of the most important platforms, such as:

EUMETSAT – is an intergovernmental organisation and was founded in 1986. Our purpose is to supply weather and climate-related satellite data, images and products – 24 hours a day, 365 days a year – to the National Meteorological Services of our Member and Cooperating States in Europe, and other users worldwide.

The SODA service - is a broker to a list of services and web services. It offers a one-stop access to a large set of information relating to solar radiation and its use. This is an Intelligent System (SoDa-IS) that builds links to other resources that are located in various countries [38].

ECMWF - The European Centre for Medium-Range Weather Forecasts is an independent intergovernmental organization supported by 34 states.

E. Progressive integration of PV systems in electricity market to maintain the grid stability

The subject of grid integration coupled with renewable power generation is playing an increasingly important role. The optimum integration of the decentralized and variable power generation capacity of PV systems into the existing distribution grid (designed for unidirectional flows of power) is as crucial as it is pressing for that very reason. There are already progressive approaches for the optimum grid integration of renewable power generation capacity that go beyond both directives: Comprehensive energy management at the household level, the incorporation of solar radiation forecasts, and the use of local storage systems are paving the way to the intelligent grid, the “smart grid”. SMA is also committed to this field – with the development of the innovative Sunny Home Manager, the collaboration with PV forecast services, or the advancement of the proven Sunny Backup system for a grid-connected storage solution [39].

3. MODELING AND SIMULATION OF PV PARK USING SPECIALIZED SOFTWARE TOOLS

3.1 Preliminary

At the present time there are sizing tools of photovoltaic systems available on the market, taking into account the proposed energy consumption, site localization and system cost [40]. Many of the specialized programs are relatively simple and allow the user to solve automatically the energy balance calculations, basing on different components of the photovoltaic system [41].

There were analysed the most common specialized programs, namely SAM, SOLARIUS PV and PVSyst in order to dimension photovoltaic systems. The results obtained through numerical modeling were compared with the existing data from a photovoltaic park installed in the South of Romania. In this way it was identified the most efficient program for sizing.

3.2 The SAM (Solar Advisory Model) software. Simulation results

SAM, called "Solar Advisory Model" was firstly developed (for internal use only) by the National Renewable Energy Laboratory (NREL), in cooperation with the Sandia National Laboratories, in 2005 [42, 43], NREL has released the first public version of SAM in August 2007, in order to be used by solar energy experts for the technical – economic analysis of PV systems. The program allows the performance forecasts and energy estimates for photovoltaic systems, both for grid connected or mixed photovoltaic systems, and stand-alone ones, based on the technical and economical parameters to be used as input for analysis.

The aim of the program is to facilitate the decision making for persons involved in the renewable energy industry. It could be used by the project managers, researchers, engineers, financial experts and developers of new technologies [44, 45]. SAM makes performance forecasts and estimates the cost of power installations connected to the grid or stand-alone, based on the costs of installing, operating and specific design parameters.

National Renewable Energy Laboratory (NREL) distributes the software SAM at: https://sam.nrel.gov. https://sam.nrel.gov/content/sam-publications

Based on this program, it is possible to calculate the electricity output of the PV systems from hour to hour; it can be exploited the performance characteristics of the system by visualization of the hourly and monthly data from the tables and graphs in order to establish the system performance and annual capacity [46, 47].

The input data from our study are represented by the main specifications of the Photovoltaic Park sited in the South of Romania (see **Tab. 3.1.**); they are compared with the data obtained from numerical modeling using SAM program. The meteorological parameters interesting for our location are direct solar irradiance, average annual temperature, average annual wind speed and albedo.

Direct irradiance	Average annual temperature	Average annual wind speed	Albedo
1 kWh/m²/day	**11.5 ˚C**	**3.2 m/s**	**0.2**

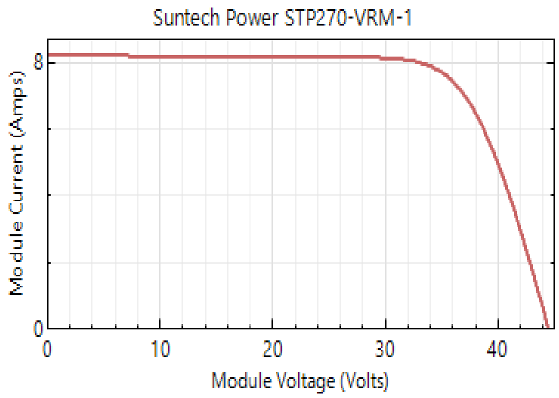
Tab. 3.1: The main specifications of the PV system for the studied PV Park [33]

Installed power	**9934 kW**
PV panel power	245 245 Watt Suntech Power
Total number of panels	40551
Number of panels on string	21
Number of strings	1931
Number of inverters	20 - Green Power PV500
Used area	33 ha

The PV power plant is composed from 1931 strings, each string having 21 Suntech panels of 245W each. Totally there are 40551 PV panels having an installed power of 9934 kW. The solar radiation data are measured done by 2 pyranometers and 10 cells for calibration.

The pyranometers are located within the weather station in the PV Park and the cells for calibration are placed at each transformation center. PV panels are made of 72 solar cells based on Si polycrystalline. The I-V characteristic of a PV module is presented in **Fig. 1.**

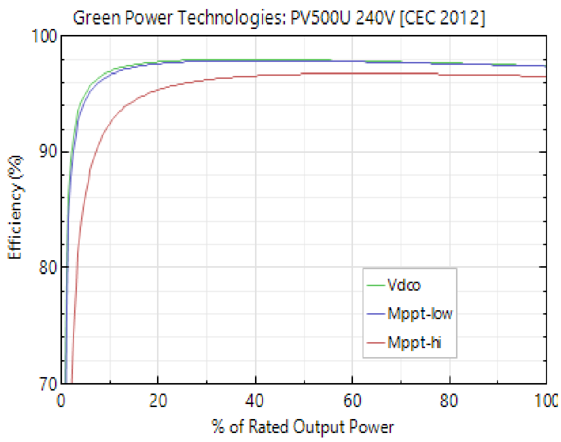
The PV module main parameters are considered for Standard Test Conditions (STC): total irradiance of 1000W/m^2 and cell temperature of 25ºC (See **Tab. 3.2**).



Tab. 3.2: PV module main parameters	
Nominal efficiency	13.9098%
Maximum power	269.85 Wdc
Maximum voltage	35 Vdc
Maximum current	4.8 Adc
Voltage in open circuit	44.5 Vdc
Short-circuit current	8.2 Adc

Fig. 3.1: I-V characteristics of the PV module [33]

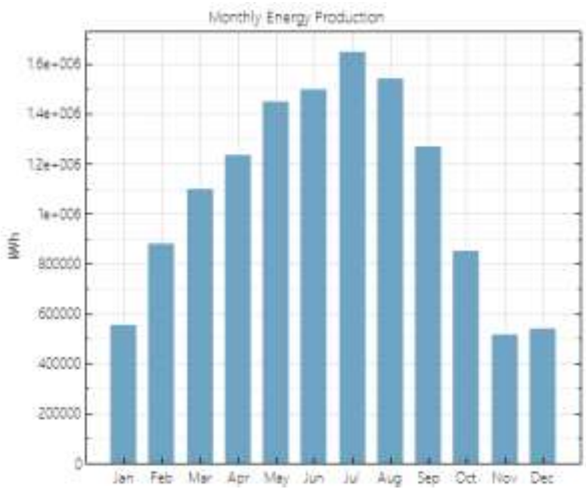
The PV system includes, too 20 Green Power inverters of PV500 type (the efficiency curve of an inverter is shown in **Fig. 3.2**). Each transformation center contains 2 inverters. The inverter main parameters are presented in **Tab. 3.3.**



Tab. 3.3: Inverter main parameters	
CEC Efficiency	97.733%
EURO Efficiency	97.656%
Max. power output ac	500000Wac
Maximum power dc	513270 Wdc
Normal operating power consumption	998.728 Wdc
Night operating power consumption	140.4 Wac
Nominal voltage ac	240 Vac
Maximum voltage dc	1000 Vdc
Minimum current dc	1250 Adc
Minimum voltage MPPT	425 Vdc
Nom. voltage 12v dc	395.616 Vdc
Maximum voltage MPPT	825 Vdc

Fig. 3.2: The PV500 Green Power Inverter Efficiency [33]

In **Fig. 3.3** is represented simulated monthly energy production using SAM software. The simulation was carried out over a period of a year; the results are adjusted using an annual degradation coefficient of 0.5% per year.



SAM Energy production [MWh]
556.07
880.84
1095.69
1235.40
1447.85
1495.60
1646.23
1542.12
1267.53
849.48
513.89
538.76
13069

Fig. 3.3: SAM monthly energy production [33]

The losses caused by various factors-both technical, and external ones from the environment of the system location were taken into account. In order to make a comparison between actual and simulated data, the components of the existing PV system and those used in simulation are identical.

In terms of losses arising in the system functionality, the program calculates their estimates based on the existing literature and data on the technical details of the used components. In addition to the technical factors, the program estimates other type of losses that may be due to the environment in which the system is located.

In the database relating to the sizing program, the same types of panels, strings, inverters from the studied PV Park have used. We have to mention that the weather data from the

SAM software are different from those existing in the database of meteorological station of the PV Park. The energy to be injected in SEN (National Energy System) based on the SAM software presents an annual difference of 1020 MWh compared with the actual one.

All of these losses are represented in a Sankey diagram, (see **Fig. 3.4**) and according to this, the user can estimate the future problems and differences between the installed power of the system and the energy actually delivered to the local grid of energy distribution.

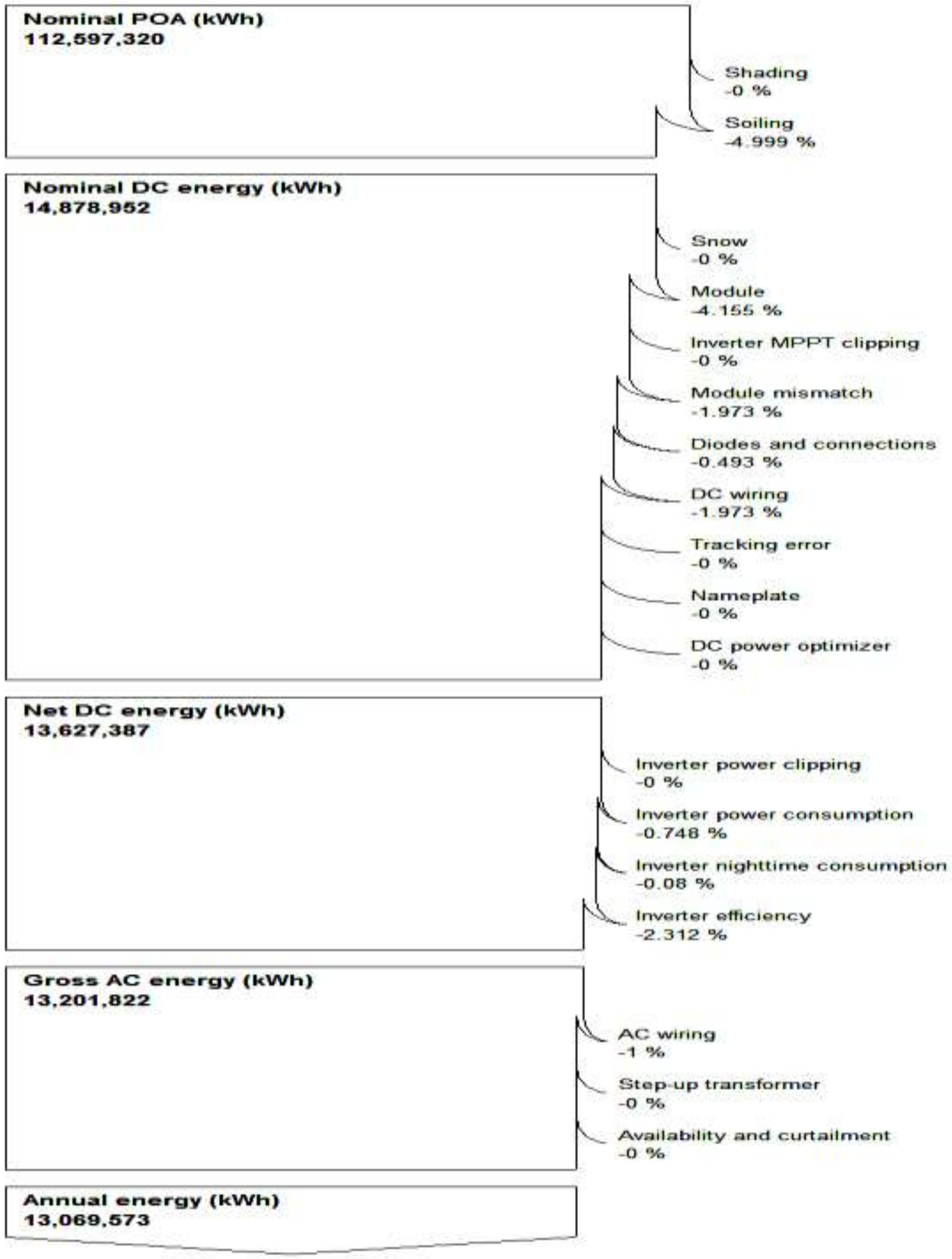


Fig. 3.4: Sankey diagram for energy losses [33]

3.3 The SOLARIUS-PV software. Simulation results

The program SOLARIUS – PV represents a software package for the design and simulation of energy production for PV systems connected to the grid. It has multiple functions to be fulfilled for a better sizing [48, 49]

a) *Calculator for estimation of solar irradiance.* The SOLARIUS software guides the user for the sizing process in order to obtain the best technical and financial solutions. The program provides the ability to view real-time possible benefits of changes that the user could enter. For example, the benefits obtained by the optimum changing of the tilt angle for PV panels on a monthly time period of one year, could be remarked

b) The CAD (computer aided design) input files parameters

c) *Calculations of the efficiency rate of the PV system.* The SOLARIUS software calculates annual and hourly energy production for a PV system. In this way there is obtained its profitability based on the recovery period that determines the PV system simulated performance (**Fig. 5**). This technical and financial evaluation is simple and fast, the program generating system yields through various charts and tables, easy to understand even for new users.

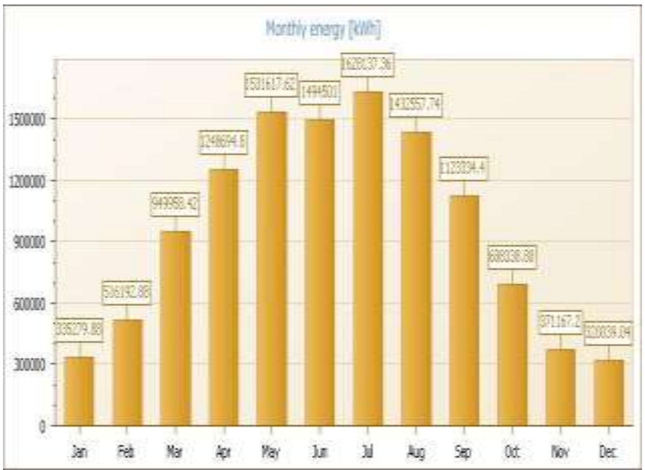
d) Analysis of the losses

e) *Automatic sizing and positioning of the photovoltaic panels.* The SOLARIUS software works in graphic mode to be faster and easier for understanding. The program sizes and automatically places the PV panels on the selected location (roof, fixed mounting systems or solar trackers). The panels to be used in the construction of the system can be selected from an existing archive, which can be updated easily and from which you can extract information about the technical specifications of these panels. Within the framework of appropriate size and location of the PV system, it is possible to sketch the site plan and PV panel location.

f) *Auto - size of the inverters.* The PV systems can be sized by SOLARIUS software, integrating single phase or three phase inverters or inverters based on MPPT (Maximum Power Point Tracking) technology. In order to achieve maximum efficiency, inverters can be chosen from a list of components but, depending on the characteristics of the system, the program can propose the best options to maximize the yield of the inverters.

The reflection capacity of solar energy within the incident surface is characterized by *albedo*. The albedo depends on many factors such as soil nature, its degree of roughness and soil color. In this study the albedo value was considered to be 0.2.

The monthly energy production based on SOLARIUS software is shown in **Fig. 3.5.**



SOLARIUS – PV energy [MWh]
335.28
516.19
949.96
1248.69
1531.61
1494.50
1628.14
1432.55
1123.33
688.34
371.16
320.09
11639

Fig.3.5: SOLARIUS – PV monthly energy production [33]

The simulated annual energy to be injected into the SEN is 11639 MWh. The BOS components are identical to those of the existing PV Park. There is a difference of 410 MWh between the simulated values and existing ones.

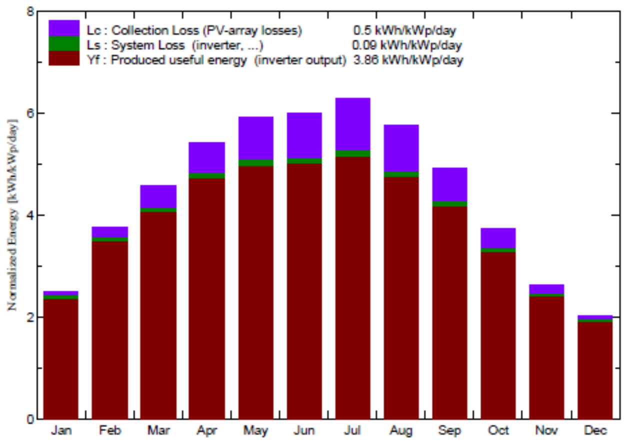
In terms of annual energy production, we conclude that the SOLARIUS software has better results in comparison with the SAM one because the energy production value provided by SOLARIUS is approaching to the value supplied by the PV Park.

3.4 The PVSyst software. Simulation results

The PVSyst software is a package intended for study, sizing and data analysis of a photovoltaic system (grid connected or stand-alone PV systems). For analysis meteorological global database and databases containing detailed specifications of the system components are used. The software holds two expertise technical levels for sizing of a PV system, each level corresponding to different stages in the development of a real system [50, 51].

Preliminary Design - is appropriate to the pre-dimensioning stage. In this level, the PV system performance is assessed using the average monthly values, without detailed specification of the components of the system. For PV systems connected to the grid, in particular for BIPV systems, this level has architectural guidance, requiring information on available space, photovoltaic technology used (color, transparency, etc.), the required power and financial details [52, 53] For stand-alone systems a sizing of power generated or storage batteries, taking into account the load profile and loss of load probability could be achieved [54]

Project Design – The project aims to carry out a detailed examination using hourly simulations and selection of different specific components of PV system. The program helps the user in sizing the PV system (number of PV modules used and their layout-in series or in parallel); there are considered data related to the inverters, batteries or project needs.



PVSyst energy production [MWh]
613.12
816.08
1049.45
1183.21
1286.56
1254.12
1334.63
1229.47
1044.16
849.58
605.01
493.27
11758

Fig. 3.6: PVSyst monthly energy production [33]

On this basis the PVSyst software is developing monthly energy production (see **Fig. 3.6**), and losses Sankey diagram (see **Fig. 3.7**).

There is a difference of 395 MWh between the simulated yearly energy (injected into the SEN) and the real one supplied by the PV Park. This value of 11758 MWh obtained using the PVSyst software is the closest to the value obtained in situ, respectively 12049 MWh, thus the PVSyst software, is the most corresponding for estimation of annually energy production by a PV Park.

The results simulated using the three programs: SOLARIUS, SAM and PVSyst are compared with the measured data for the studied PV Park (see **Tab. 3.4** and **Fig. 3.8**)

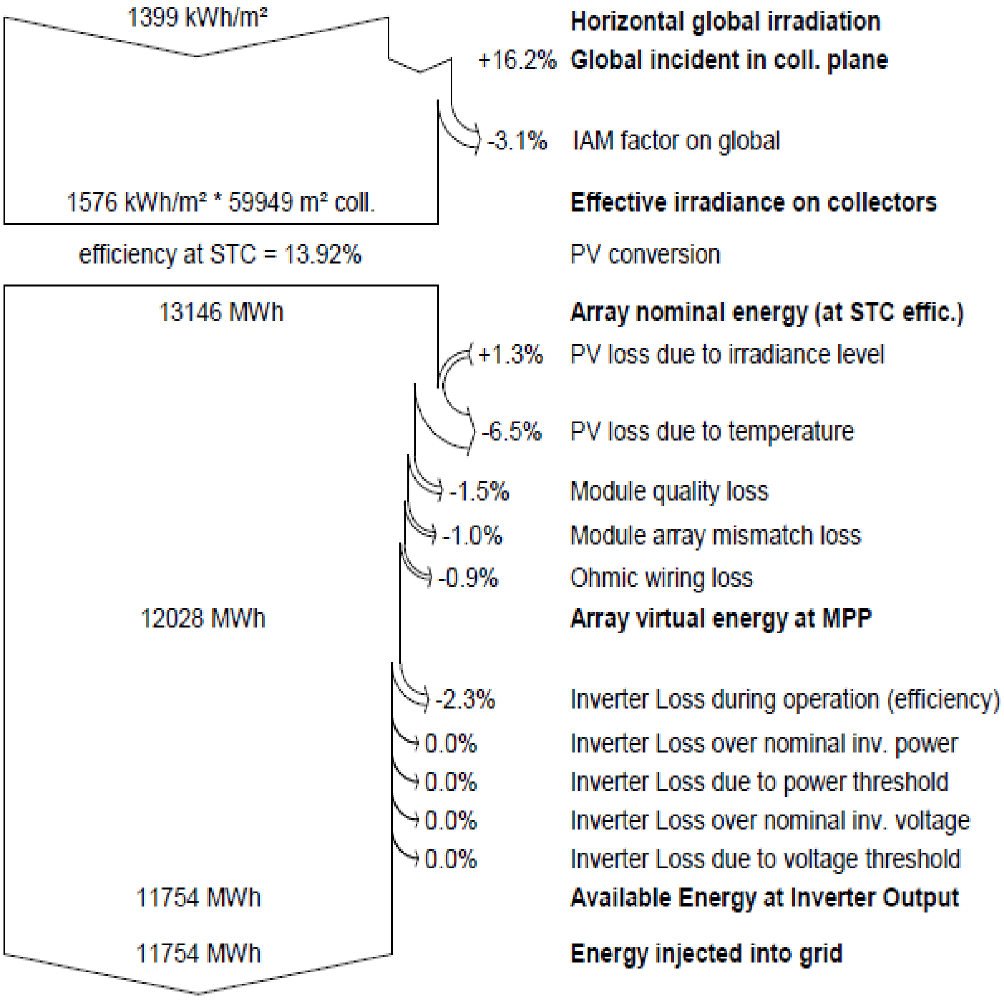


Fig. 3.7: Sankey diagram for energy losses [33]

2.2. Comparative results.

The monthly/annually energy production injected into the grid; are calculated in the Tab. 4. There are considered both measurement data, and simulated results by the three studied programs.

Tab. 3.4: Monthly/annually energy injected into to the grid: measured data and simulated results by three programs SAM, SOLARIUS and PVSyst [33]

Month / Database	Measured energy [MWh]	Simulated energy with SAM [MWh]		Simulated energy with SOLARIUS [MWh]	Simulated energy with PVSyst [MWh]
January	347.33	556.07		335.28	613.12
February	585.39	880.84		516.19	816.08
March	1273.83	1095.69		949.96	1049.45
April	1094.03	1235.40		1248.69	1183.21
More	1442.60	1447.85		1531.61	1286.56
June	1422.56	1495.60		1494.50	1254.12
July	1507.23	1646.23		1628.14	1334.63
August	1671.89	1542.12		1432.55	1229.47
September	1197.59	1267.53		1123.33	1044.16
October	922.31	849.48		688.34	849.58
November	217.65	513.89		371.16	605.01
December	367.05	538.76		320.09	493.27
Total annual	**12049**	**13069**		**11639**	**11758**

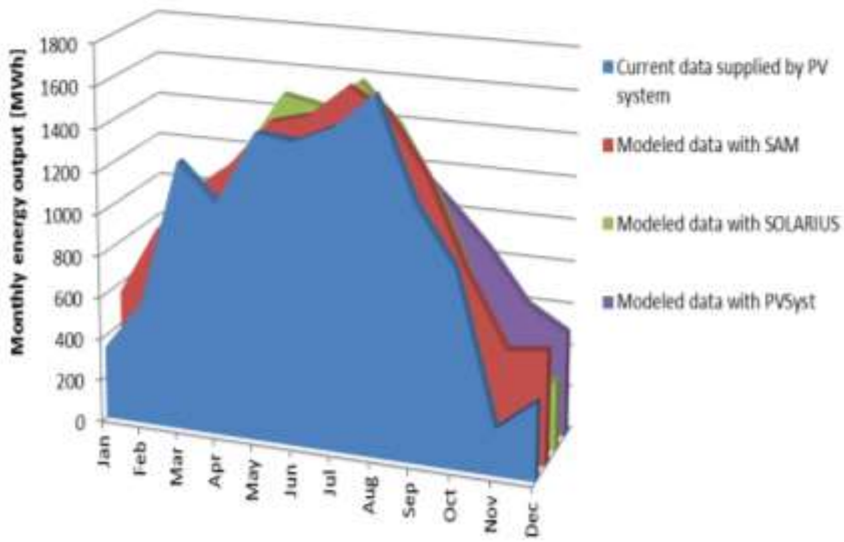


Fig. 3.8: Monthly energy production related to the analyzed PV Park using three specialized software (SAM, SOLARIUS – PV and PVSyst) compared with the monthly energy production registered by the PV system, all results are obtained within one year (2015) [33]

4. CONCLUSIONS

The third generation of advanced solar cells was developed the last two decades with very good premises for its industrial implementation on middle and long term. One of the tasks of the research in solar cells technologies is to overcome Shockley-Queisser conversion efficiency limitation based on the progressive introduction of quantum dot, intermediate band, hot carrier solar cells a.o.

At the same time the main trends in PV modules and systems are represented by: solar resource data, spectral corrections, energy losses (soiling is the main source), bifacial technology and monitoring & validation studies.

The comparative analysis of the three discussed software (SAM, SOLARIUS-PV and PVsyst) puts in evidence that for the annual level, the closest results with the measured ones in the analyzed PV Park are based on the PVSyst software.

The SAM program could be recommended to optimize the existing PV Park, because it offers the highest annual simulated energy production. A reconditioning of the actual PV Park could be taken into account.

The programs could not be used for forecasts on short and medium term because the errors are significant in these cases, but on the long term (one year) they would offer an acceptable perspective of the results.

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