ESTIMATION OF ELECTRICITY PRODUCTION FOR A PHOTOVOLTAIC PARK USING SPECIALIZED ADVANCED SOFTWARE

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Abstract

Modeling and simulation of photovoltaic systems represent an essential task for the integration of photovoltaic panels in current power applications. 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. 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.

In this article, there were considered the most common specialized programs namely SAM, SOLARIUS PV and PVSyst; it was analysed the sizing of a photovoltaic system. 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.

Keywords: *PV system, the Photovoltaic Park, simulation, modeling, software tools*

1. Introduction

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 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 (Fara, et al., 2009; Sharma, et al., 2014)

2. Presentation and results of the SAM software (Solar Advisory Model)

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 (https://sam.nrel.gov; Wagner and Gilman, 2011). NREL has released the first public version of SAM in August 2007, in order to be used by solar energy experts for the technical – economical 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 (Klise and Stein, 2009; Wagner and Zhu, 2011). SAM makes performance forecasts and estimates the cost of power installations connected to the grid or stand-alone, based on the costs of installing,

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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 (Wagner 2012; Gilman and Flat 2013). The input data from our study are represented by the main specifications of the Photovoltaic Park sited in the South of Romania (see **Tab. 1**); they are compared with the data obtained from numerical modeling using SAM program. The meteorological parameters interesting for the PV Park's location are: direct irradiance - 1 [kWh/m^2/day], average annual temperature – 11.5 [˚C], average annual wind speed – 3.2 [m/s] and Albedo – 0.2. These parameters were introduced to describe a general view of the site where the PV system is located. The comparative study between the measured data and simulated ones by means of specialized software programs for determination of monthly/yearly electricity production does not take into account the meteorological parameters of the analyzed existing PV Park because the simulation programs have own meteorological data and different models were used for calculation of electricity production; the authors' main objective was to interfere as little as possible in the characteristics of the simulation programs.

Tab. 1: The main specifications of the PV system for the studied PV Park

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 characteristics 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 25^{o}C (See **Tab. 2**).

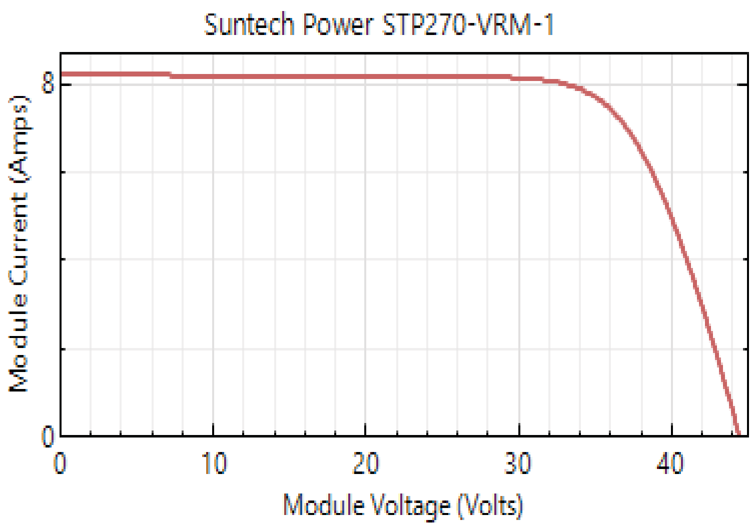

Fig. 1: I-V characteristics of the PV module

The PV system includes, too 20 Green Power inverters of PV500 type (the efficiency curve of an inverter is shown in **Fig. 2**). Each transformation center contains 2 inverters. The inverter main parameters are presented in **Tab. 3.**

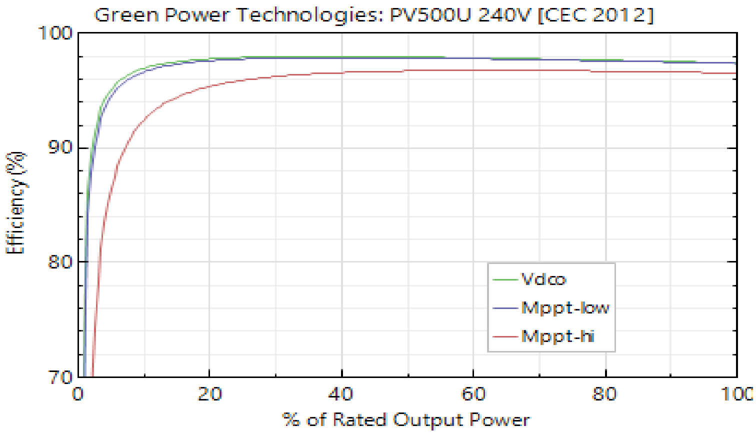

Fig. 2: The PV500 Green Power Inverter Efficiency

Tab. 2: Main parameters for PV module

PV module	
Nominal efficiency	13.9098%
Maximum power	269,850 W dc
Maximum voltage	35 V dc
Maximum current	4.8 A dc
Voltage in open circuit	44.5 V dc
Short-circuit current	8.2 A dc

Tab. 3: Main parameters for inverter

Inverter	
CEC Efficiency	97,733%
EURO Efficiency	97,656%
Max. power output ac	500000W ac
Maximum power dc	513270 W dc
Normal operating power consumption	998,728 W dc
Night operating power consumption	140.4 W ac
Nominal voltage ac	240 V ac
Maximum voltage dc	1000 V dc
Minimum current dc	1250 A dc
Minimum voltage MPPT	425 V dc
Nom. voltage 12v dc	395,616 V dc
Maximum voltage MPPT	825 Vdc

In **Fig. 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.
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. All of

these losses are represented in a Sankey diagram, (see **Fig. 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.

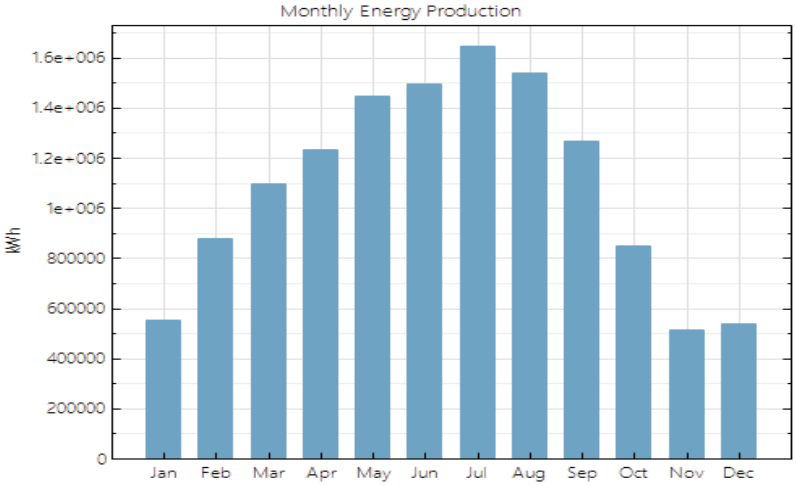

Fig. 3: SAM monthly energy production

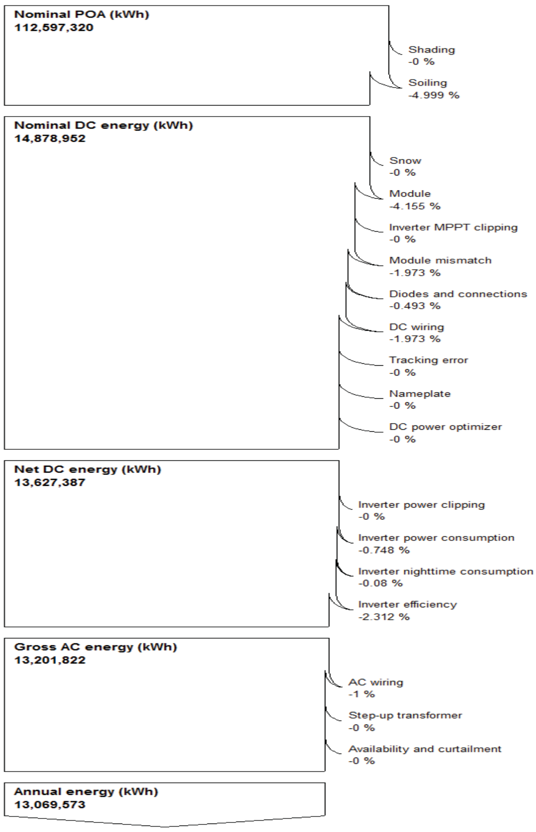

Fig. 4: Sankey diagram for energy losses

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.

3. Presentation and results of the software SOLARIUS-PV

The program SOLARIUS – PV represents a software package for the design and simulation of energy production for PV systems connected to the grid (http://www.acca.it). It has multiple functions to be fulfilled for a better sizing (ACCA Software, Solarius PV, User's Guide, 2011):

- **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. 5.**

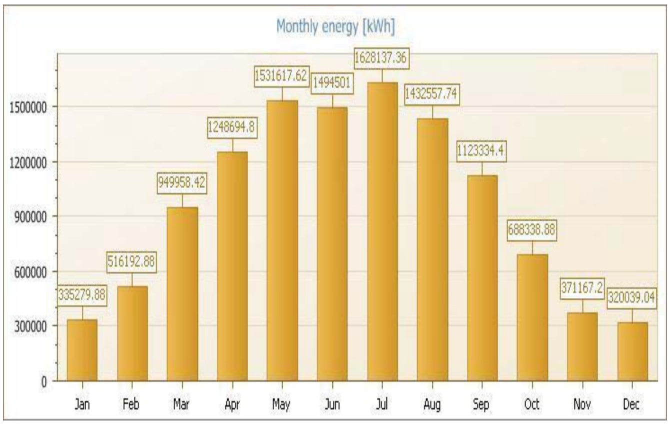

Fig. 5: SOLARIUS – PV monthly energy production

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.

4. Presentation and results of the software PVSyst

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 (http://www.pvsyst.com; Chikh et al., 2011).

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 (Karki et al., 2012; Iftakhar et al., 2012). 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 (Irwan et al., 2015).

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. On this basis, the PVSyst software is developing monthly energy production (see **Fig. 6**), and losses Sankey diagram (see **Fig. 7**).

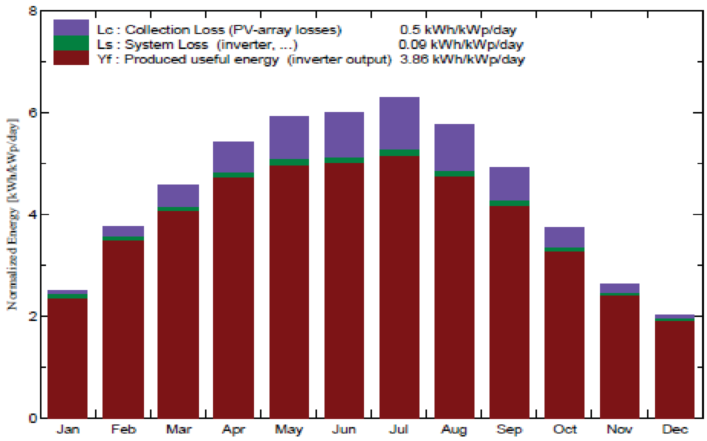

Fig. 6: PVSyst monthly energy production

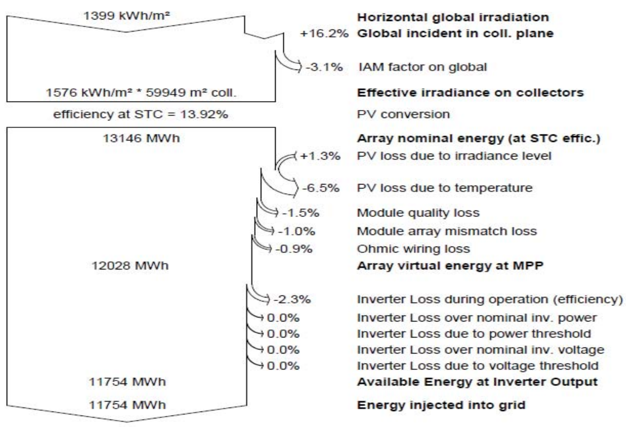

Fig. 7: Sankey diagram for energy losses

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.

5. Analysis of the results

The simulated results using the three software programs: SOLARIUS, SAM and PVSyst were compared with the measured data for the studied PV Park (see **Tab. 4** and **Fig. 8**). There were obtained too, the absolute and relative errors for annual energy production estimation using the analyzed simulation programs, namely: 1) For SAM software the absolute error is 1020 MWh and the relative error is 8.47 %, 2) For SOLARIUS software the absolute error is 409.62 MWh and the relative error is 3.4 %, 3) For PVSyst software the absolute error is 290.80 MWh and the relative error is 2.41 %. According to the obtained results the PVSyst software has the smallest error in comparison with the measured data; it is the most efficient program to be used in the simulation of energy production estimation on long term (annually).

Tab. 4: Monthly/annually energy injected into to the grid: measured data and simulated results by three programs SAM, SOLARIUS and PVSyst

Month / Database	Measured energy production [MWh]	Simulated energy production with SAM [MWh]	Simulated energy production with SOLARIUS [MWh]	Simulated energy production 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**

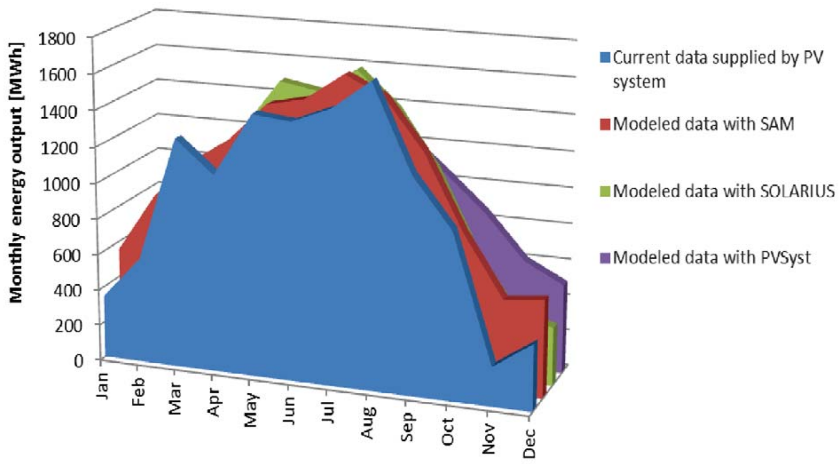

Fig. 8: Monthly energy production related to the analyzed PV Park using three specialized software (SAM, SOLARIUS – PV and PVSyst) compared with the monthly energy production registered by the PV system, all results are obtained within one year (2015)

6. Conclusions

- The comparative analysis shows that for the annual level, the closest results from 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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