

DESIGN OPTIMIZATION AND SIMULATION OF THE PHOTOVOLTAIC SYSTEMS ON BUILDINGS IN SOUTHEAST EUROPE

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ABSTRACT

The favourable climate conditions of the Southeast Europe and the recent legislation for the utilization of renewable energy sources provide a substantial incentive for the installation of photovoltaic (PV) systems. In this paper, the simulation of a grid-connected photovoltaic system is presented with the use of the computer software package PVsyst and its performance is evaluated. The performance ratio and the various power losses (temperature, soiling, internal network, power electronics) are calculated. There is also calculated the positive effects on the environment by reducing the release of gases that cause greenhouse effect.

KEYWORDS: Photovoltaic, PV System, Renewable Energy, Simulation, Optimization

I. INTRODUCTION

The aim of the paper is to present a design methodology for photovoltaic (PV) systems, like those of small appliances, as well as commercial systems connected to the network. It will present also the potentials of Southeast Europe (Kosova) to use solar energy by mentioning changes in regulations for initiating economic development. The project of installing a PV system connected to the grid, which is the roof type, will have to respond to the requests:

1. What is the global radiation energy of the sun
2. What is the maximum electrical power which generates the PV system
3. What is the amount of electrical energy that the system produces in a year
4. What is the specific production of electricity
5. How much are the losses during the conversion in PV modules (thermal degradation, the discrepancy).
6. How much are the values of loss factors and the normalized output
7. What is the value of the Performance Ratio (PR)
8. How much are the losses in the system (inverter, conductor, ...)
9. What is the value of energy produced per unit area throughout the year
10. What is the value of Rated Power Energy
11. What is the positive effect on the environment

We want to know how much electricity could be obtained and how much will be the maximum power produced by photovoltaic systems connected to network, build on the Laboratory of Technical Faculty of Prishtina, Prishtina, Kosovo.

Space has something over 5000 m² area, and it has no objects that could cause shadows. We want to install panels that are in single-crystalline technology and we are able to choose from the program library. Also the inverters are chosen from the library.



Figure 1. Laboratory conceptual plan for PV system on the roof. Photo taken from Google Map

In the next chapter, the similar and related projects are mentioned and we can study the explained results through the references. In the material and methods is explained the use of the software for simulation the design and use of a PV system. In results chapter the detailed report explains all parameters and results of the simulation. All the losses and mismatches along the system are quantified, and visualised on the "Loss Diagram", specific for each configuration.

II. RELATED WORK

In the paper "Performance analysis of a grid connected photovoltaic park on the island of Crete" [2], the grid-connected photovoltaic park (PV park) of Crete has been evaluated and presented by long term monitoring and investigating. Also, the main objective of the project "Technico-economical Optimization of Photovoltaic Pumping Systems Pedagogic and Simulation Tool Implementation in the PVsyst Software" [9], is the elaboration of a general procedure for the simulation of photovoltaic pumping systems, and its implementation in the PVsyst software. This tool is mainly dedicated to engineers in charge of solar pumping projects in the southern countries.

III. MATERIALS AND METHODS

Within the project we will use the computer program simulator PVsyst, designed by Energy Institute of Geneva, which contains all the subprograms for design, optimization and simulation of PV systems connected to the grid, autonomous and solar water pumps. The program includes a separate database for about 7200 models of PV modules and 2000 models of inverters.

PVsyst is a PC software package for the study, sizing, simulation and data analysis of complete PV systems. It is a tool that allows to analyze accurately different configurations and to evaluate its results in order to identify the best technical and economical solution and closely compare the performances of different technological options for any specific photovoltaic project. Project design part, performing detailed simulation in hourly values, including an easy-to-use expert system, which helps the user to define the PV-field and to choose the right components. Tools performs the database meteorological and components management. It provides also a wide choice of general solar tools (solar geometry, meteorological on tilted planes, etc), as well as a powerful mean of importing real data measured on existing PV systems for close comparisons with simulated values. Besides the Meteorological Database included in the software, PVsyst now gives access to many meteorological data sources available from the web, and includes a tool for easily importing the most popular ones.

The data for the parameters of location: Site and weather: Country: KOSOVO, Locality: Prishtina, Geographic coordinates: latitude: 42°40'N, longitude: 21°10' E, altitude: 652m. Weather data: Prishtina_sun.met:Prishtina, Synthetic Hourly data synthesized from the program Meteororm'97. Solar path diagram is a very useful tool in the first phase of the design of photovoltaic systems for determining the potential shadows. Annual global radiation (radiant and diffuse) for Prishtina is 1193 [kWh/m².year]. The value of Albedo effect for urban sites is 0.14 to 0.22; we will take the average 0.2. [1]

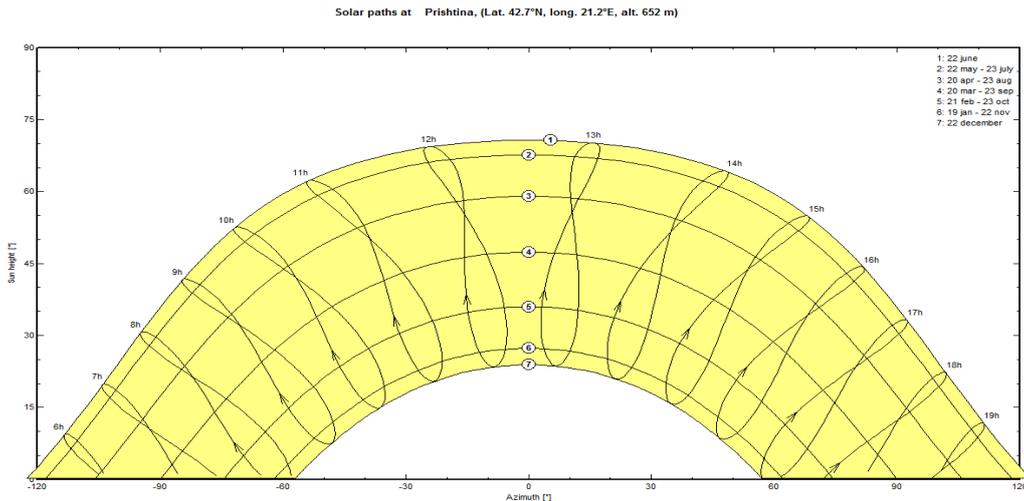


Figure 2. The diagram of sun path for Prishtina (42°40' N, 21°10' E)

Transposition factor = 1.07 (Transposition factor shows the relationship between radiation panels and global radiation). For grid connected system, the user has just to enter the desired nominal power, to choose the inverter and the PV module types in the database. The program proposes the number of required inverters, and a possible array layout (number of modules in series and in parallel). This choice is performed taking the engineering system constraints into account: the number of modules in series should produce a MPP voltage compatible with the inverter voltage levels window. The user can of course modify the proposed layout: warnings are displayed if the configuration is not quite satisfactory: either in red (serious conflict preventing the simulation), or in orange (not optimal system, but simulation possible). The warnings are related to the inverter sizing, the array voltage, the number of strings by respect to the inverters, etc.

Photovoltaic (PV) module solution: From the database of PV modules, we choose the model of the solar panel and that is: CS6P – 230M, with maximum peak power output of $W_p = 230W$ – Canadian Solar Inc.

Inverter solution: For our project we will choose inverter 100K3SG with nominal power $P_n=100kW$ and output voltage of 450-880V, the manufacturer Hefei. For chosen modules here are some characteristics of working conditions:

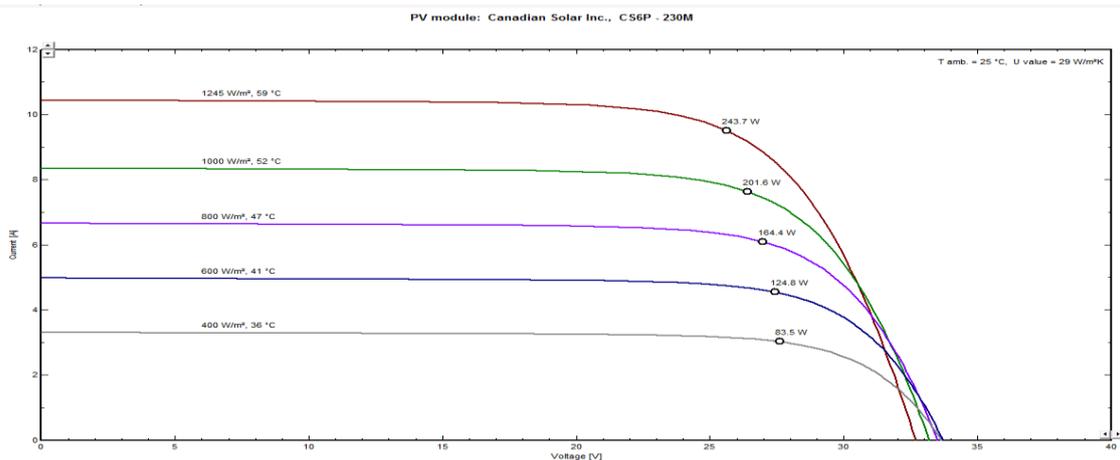


Figure 3. U-I characteristics for irradiation $h = 1245 W/m^2$ and working temperature 60°C.

Output power $P = f(U)$

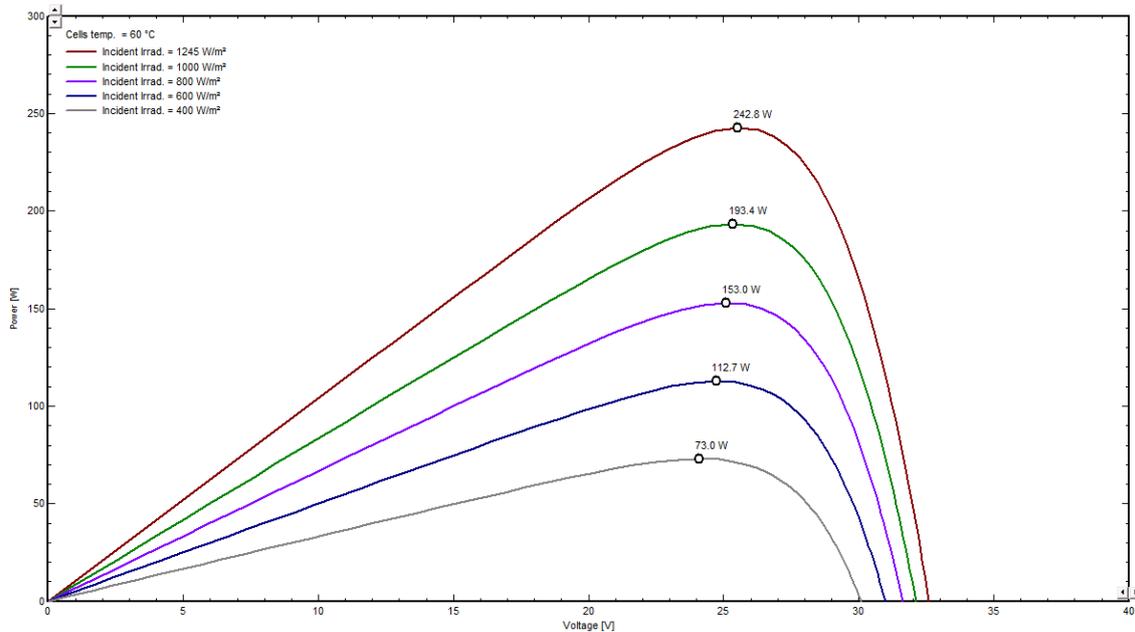


Figure 4. The characteristic of power for irradiation $h = 1245\text{W/m}^2$ and working temperature 60°C

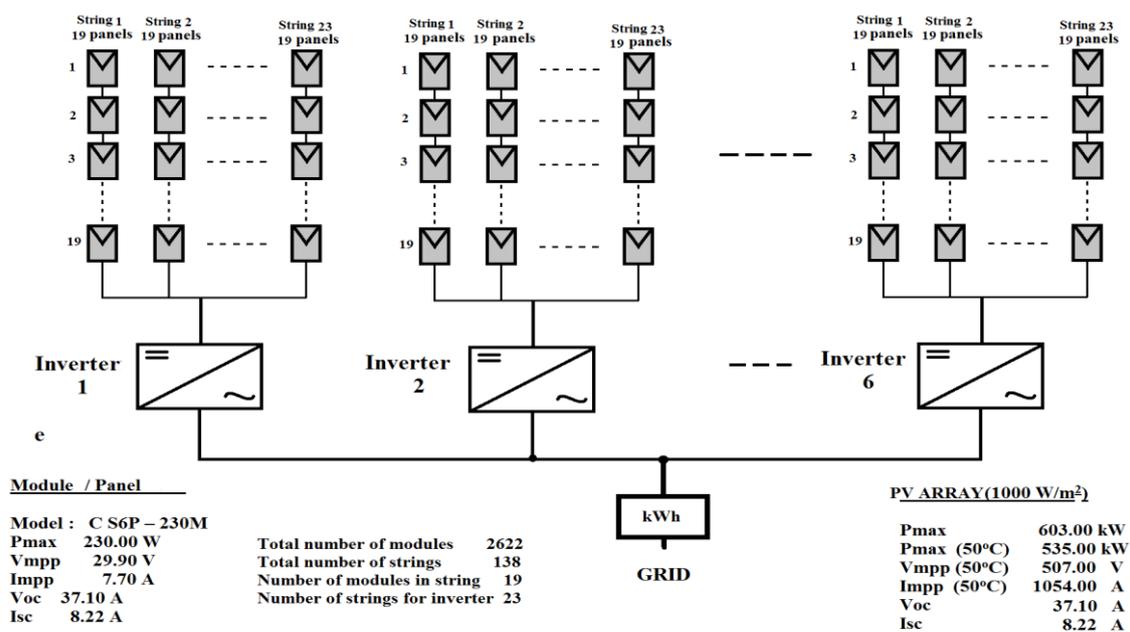


Figure 5. Blok-diagram of the PV System

Figure 5. shows the PV system is comprised of a 2622 Canadian Solar CS6P-230M monocrystalline silicon PV modules (panels). The PV modules are arranged in 138 parallel strings (string – serial connection of modules), with 19 modules (panels) in each, and connected to six Hefei 100K3SG inverters installed on the supporting structure, plus connection boxes, irradiance and temperature measurement instrumentation, and data logging system. The PV system is mounted on a stainless steel support structure facing south and tilted at 30° . Such a tilt angle was chosen to maximize yearly energy production.

IV. RESULTS

1. Global horizontal irradiation energy of the sun for a year in the territory of Eastern Europe, (specifically for Prishtina) according to results from PVsyst program is $h=1193 \text{ kWh/m}^2\text{year}$. At

the panel surface the level of radiation is 7.9% higher because the panels are tilted. This value is reduced for 3.3% because of the effect of Incidence Angle Modifier (IAM) and the final value is: $h = 1245 \text{ kWh/m}^2\text{year}$.

Reference incident energy falling on the panel's surface (in a day) is:

$Y_r = 3526 \text{ kWh/m}^2/\text{kWp/day}$. The highest value of total radiation on the panel surface is in July, 167.5 kW/m^2 , where as the lowest value is in December, 41.4 kW/m^2 . Annual irradiation is 1245 kWh/m^2 , and the average temperature is $10.26 \text{ }^\circ\text{C}$. The PV system generates 76.2 MWh of electricity in July and 20 MWh in December.

2. Maximum electric power that PV system generates in output of inverter is: $P_{nom} = 603 \text{ kWp}$.
3. Annual produced electric energy in output of inverter is: $E = 610,512 \text{ kWh}$.
4. Specific production of electricity (per kWp/year) is: $1012 \text{ kWh/kWp/year}$.
5. Losses of power during PV conversion in modules are:
 - FV losses due to radiation rate = 4.7%
 - FV losses due to the temperature scale = -4.9%
 - Losses due to quality of modules = $7976 \text{ kWh per year (1.2%)}$
 - Losses due to mis match of modules = $14334 \text{ kWh per year (2.1%)}$
 - Losses due to conduction resistance = $5174 \text{ kWh per year (0.8%)}$.
6. Loss factors and Normalised production are:
 - L_c – Panel losses (losses in PV array) = $982,006 \text{ kWh per year (13.1%)}$
 - L_s – System losses (inverter ...) = $40,904 \text{ kWh per year (6.7%)}$
 - Y_f – Useful energy produced (the output of inverter) = $610,512 \text{ kWh per year}$.
 - Loss factors and Normalised production (per installed kWp) are:
 - L_c – Panel losses (losses in PV array) per maximum power = 0.55 kWh/kWp/day
 - L_s – Losses in the system (inverter ...) for maximum power = 0.20 kWh/kWp/day
 - Y_f – Useful produced energy (the output of inverter) for maximum power = 2.77 kWh/kWp/day
7. Performance ratio (PR) is the ratio between actual yield (output of inverter) and target yield (output of PV array) [2]:

$$PR = \frac{\text{Actual Yield}_{AC}}{\text{Target Yield}_{DC}} = \frac{E}{hA\eta_{nom}} = \frac{610\,512}{1245 \times 4218 \times 0.1433} = \frac{610512}{752527} = 0.787 \text{ (78.7\%)} \quad (1)$$

8. System losses are losses in the inverter and conduction. They are $L_s = -6.7\%$.
System Efficiency (of inverters) is: $1 - 0.067 = 0.933$, or $\eta_{sys} = 93.3\%$.
Overall losses in PV array (temp, module, quality, mismatch, resistant) are: $L_c = -13.1\%$.
PV array efficiency is: $L_c = 1 - 0.131 = 0.869$, or $\eta_{rel} = 86.9\%$.
9. The energy produced per unit area throughout the year is: [3]

$$\left(\frac{E}{A}\right) = h\eta_{pre}\eta_{rel}\eta_{sys}\eta_{nom} = PRh\eta_{nom} = 0.787 \times 1245 \times 0.143 = 140.4 \frac{\text{kWh}}{\text{m}^2} \text{ (annual)} \quad (2)$$

10. Energy for Rated Power is:

$$\left(\frac{E}{P_p}\right) = \frac{h}{H_0}\eta_{pre}\eta_{sys}\eta_{rel} = \left(\frac{E}{A}\right) \frac{h}{H_0\eta_{nom}} = PR \frac{h}{H_0} = 0.787 \times \frac{1245}{1000} = 0.9798 \text{ (97.98\%)} \quad (3)$$

11. Economic Evaluation. With the data of retail prices from PV and inverter stock market we can make estimation for the return of investment [4]:

Panels: $2622(\text{mod}) \times 1.2 \text{ (Euro/Wp.mod)} \times 230 \text{ (WP)} = 723672 \text{ Euro}$

Inverters: $6 \times 5200 \text{ (Euro)} = 31200 \text{ Euro}$

Cable: $2622(\text{mod}) \times 3 \text{ (euro/mod)} = 7866 \text{ Euro}$

Construction: $2622 \text{ (mod)} \times 5 \text{ (Euro/mod)} = 13110 \text{ Euro}$

Handwork: $2622 \text{ (mod)} \times 5 \text{ (Euro /mod)} = 13110 \text{ Euro}$

Total: 788958 Euro

If the price of one kWh of electricity is 0.10 Euro/kWh , then in one year will be earned [5]:

$610500 \text{ (kWh/year)} \times 0.10 \text{ (Euro/kWh)} \times 1 \text{ (year)} = 61050 \text{ (Euro/year)}$

$$\text{The time for return of investment will be : } \frac{788958}{610500 \times 0.10} = \frac{788958}{61050} = 12.9 \text{ years} \quad (4)$$

Module life time is 25 years, and the inverter live time is 5 years.

- Positive effect on the environment. During the generation of electricity from fossil fuels, as a result we produce greenhouse gases such as: nitrogen oxide (NO_x), Sulphur dioxide (SO₂) and Carbon dioxide (CO₂). Also is produced the large amount of ash that must be stored [6].

Table1.Positive effects of the PV system for environmental protection

Statistics for products by the power plants with fossil fuels (coal) with the capacity of electricity production ($E = 610.5$ MWh per year)		
Byproducts of coal power plant	Per kWh	For annual energy production of $E = 610.5$ MWh
SO ₂	1.24 g	757 kg
NO _x	2.59 g	1581 kg
CO ₂	970 g	692.2 t
Ash p	68 g	41.5 t

13. Diagrams

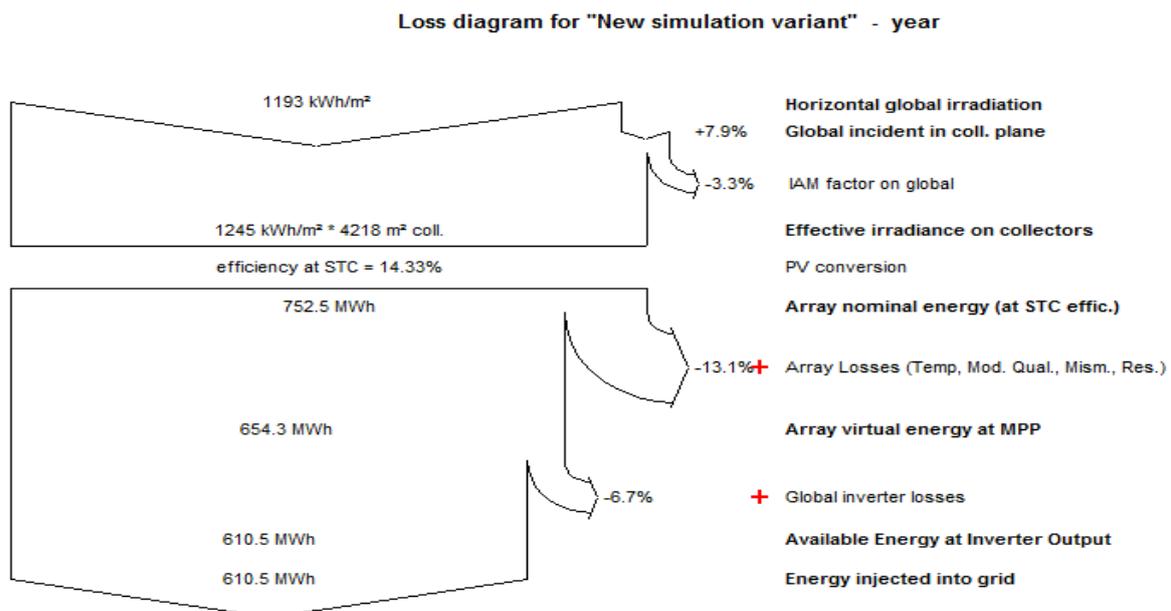


Figure 6. Diagram of system losses

The simulation results include a great number of significant data, and quantify the losses at every level of the system, allowing to identify the system design weaknesses. This should lead to a deep comparison between several possible technologic solutions, by comparing the available performances in realistic conditions over a whole year. The default losses management has been improved, especially the "Module quality loss" which is determined from the PV module's tolerance, and the mismatch on P_{mpp} which is dependent on the module technology. Losses between inverters and grid injection have been implemented. These may be either ohmic wiring losses, and/or transformer losses when the transformer is external.

Detailed loss diagram (Figure 6) gives a deep sight on the quality of the PV system design, by quantifying all loss effects on one only graph. Losses on each subsystem may be either grouped or expanded in detailed contributions.

Results - and particularly the detailed loss diagram - show the overall performance and the weaknesses of a particular design.

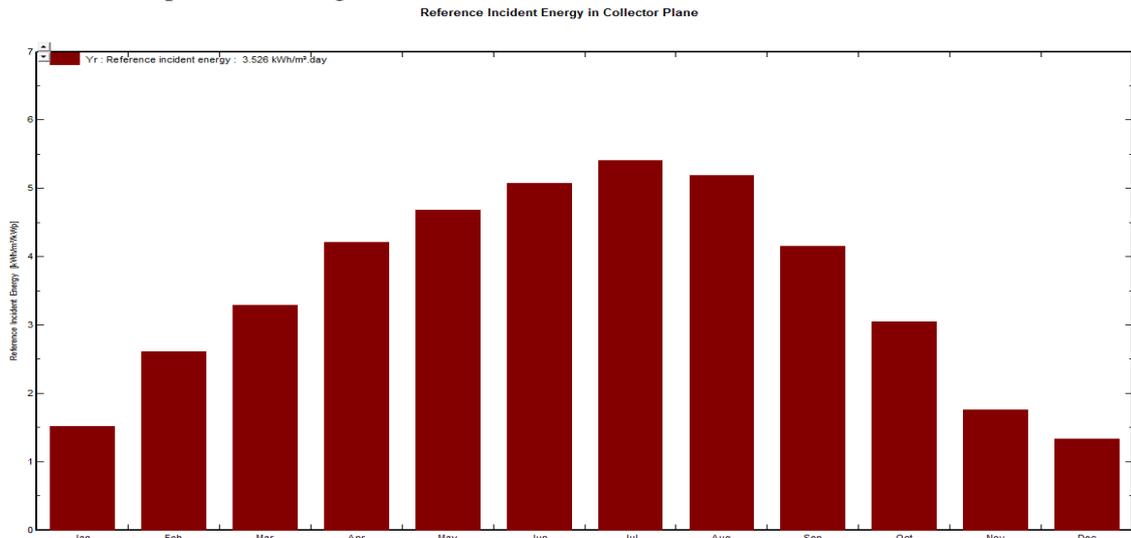


Figure 7. Reference incident Energy in collector plane

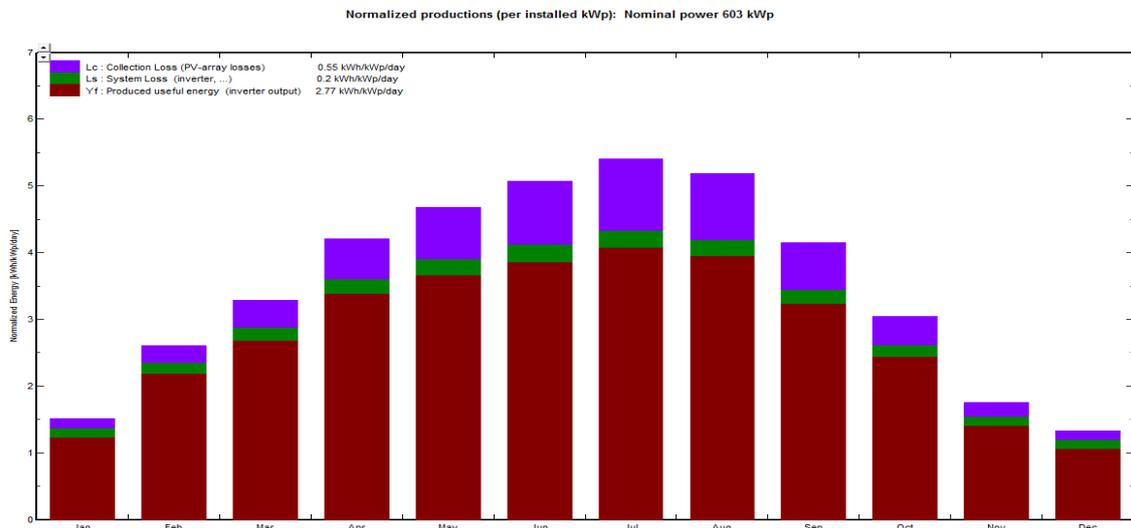


Figure 8. Normalized productions (per installed kWp)

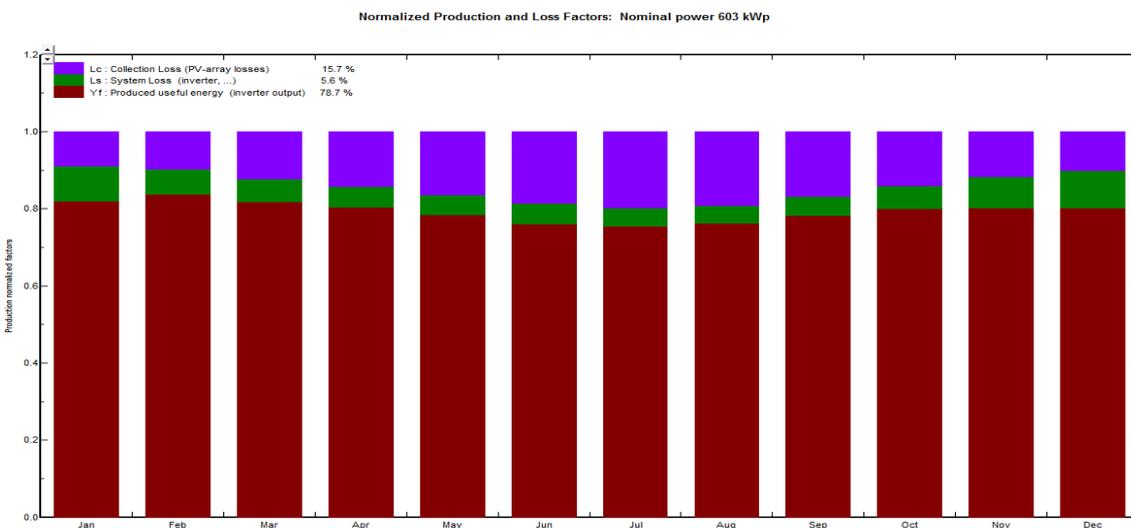


Figure 9. Normalized production and Loss factors

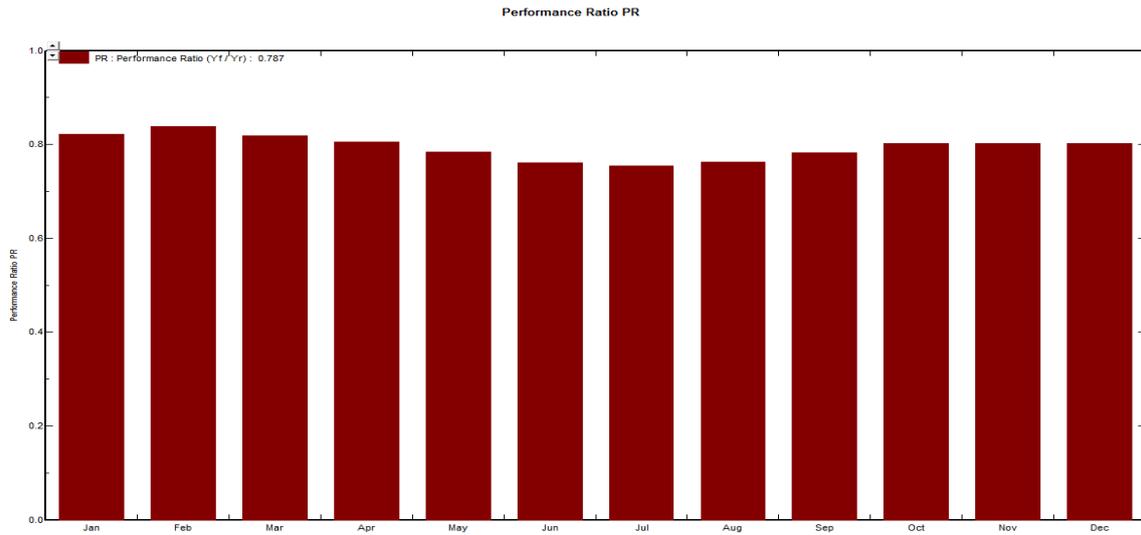


Figure 10. Performance ratio (PR)

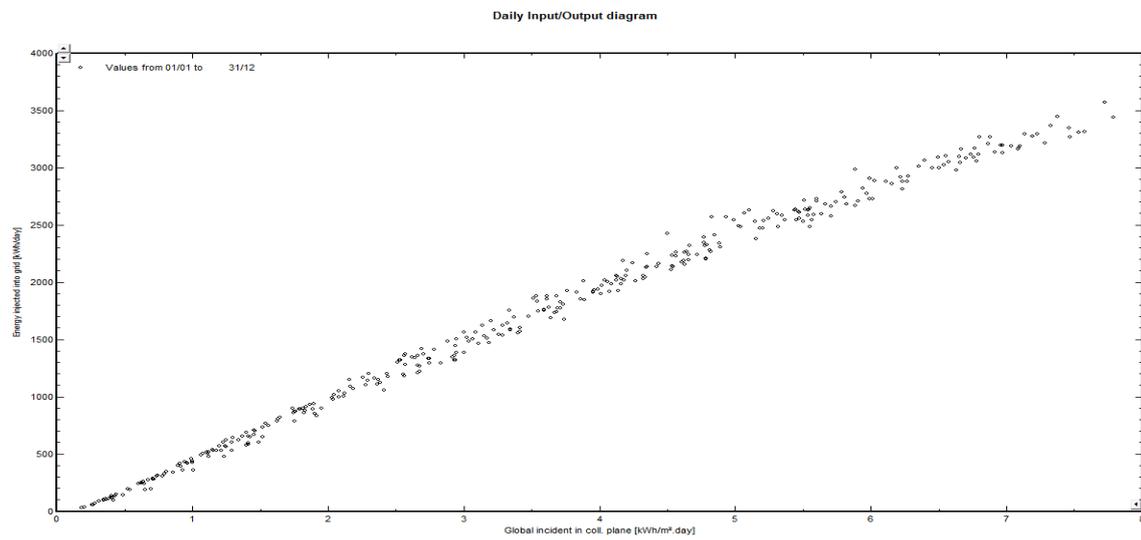


Figure 11. Daily input/output diagram

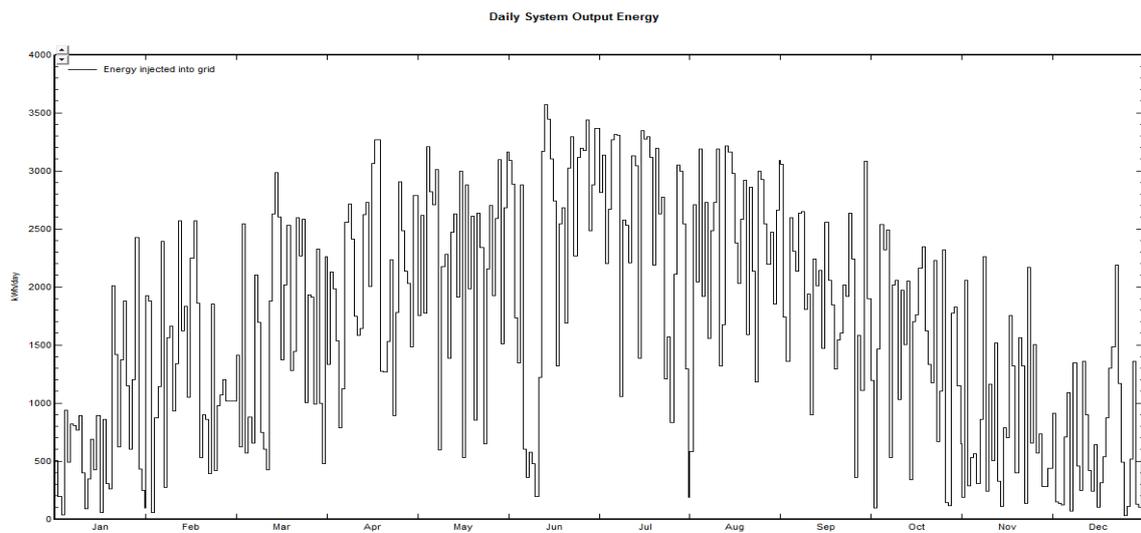


Figure 12. Daily system output energy

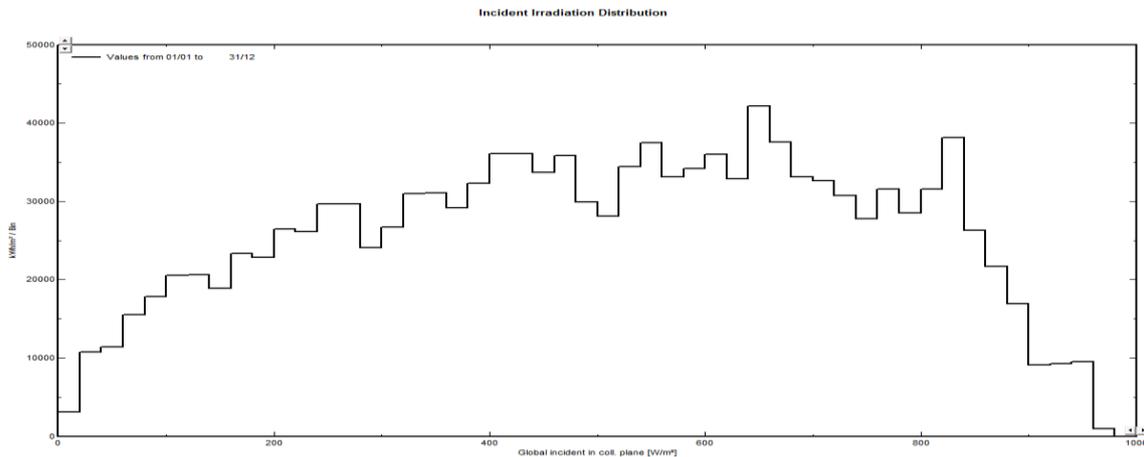


Figure 13. Incident irradiation distribution

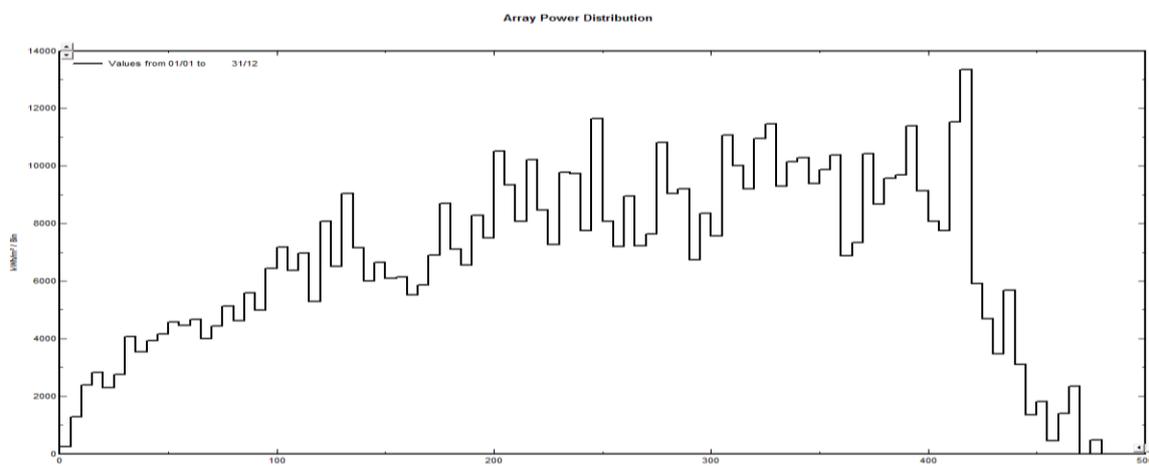


Figure 14. Array power distribution

V. CONCLUSIONS

The design, the optimization and the simulation of the PV systems for use in Southeast Europe have been analyzed and discussed, and the following conclusions are drawn: average annual PV system energy output is 1012 kWh/kWp and average annual performance ratio of the PV system is 78.7%. The performance ratio (Figure 10) shows the quality of a PV system and the value of 78.7% is indicative of good quality (Equation 1). Usually the value of performance ratio ranges from 60-80% [7]. This shows that about 21.3% of solar energy falling in the analysed period is not converted into usable energy due to factors such as losses in conduction, contact losses, thermal losses, the module and inverter efficiency factor, defects in components, etc.

It is important that we have matching between the voltage of inverter and that of the PV array, during all operating conditions. Some inverters have a higher efficiency in certain voltage, so that the PV array must adapt to this voltage of maximum efficiency. Use of several inverters cost more than using a single inverter with higher power.

In (Figure 9) is presented the histogram of the waited power production of the array, compared to the inverter's nominal power. Estimation of the overload losses (and visualization of their effect on the histogram). This tool allows to determine precisely the ratio between array and inverter P_{nom} , and evaluates the associated losses.

Utility-interactive PV power systems mounted on residences and commercial buildings are likely to become a small, but important source of electric generation in the next century. As most of the electric power supply in developed countries is via centralized electric grid, it is certain that widespread use of photovoltaic will be as distributed power generation inter-connected with these grids.

This is a new concept in utility power production, a change from large-scale central examination of many existing standards and practices to enable the technology to develop and emerge into the marketplace. [8]. As prices drop, on-grid applications will become increasingly feasible. For the

currently developed world, the future is grid-connected renewables. In the next 20 years, we can expect only a slight improvement in the efficiency of first generation (G-1) silicon technology. Will we witness a change of the dominant technology of the G-1 in an era of market share with second-generation technology (G-2), based mainly on thin-film technology (with 30% cost reduction) [9].

While these two branches will largely dominate the commercial sector of PV systems, within the next 20 years will have increased use of third generation technology (G-3) and other new technologies, which will bring to enlarge the performance or cost reduction of solar cells [10]. During this project, the overall results of the simulation system to connect to the network PV is bringing in the best conditions possible, by using the software package PVsyst [16]. Overall, the project gives them understand the principle of operation, the factors affecting positively and negatively, losses incurred before the conversion, conversion losses and losses in the cells after conversion. All this helps us to make optimizing FV systems under conditions of Eastern Europe.

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