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Causes regarding the efficiency reduction of the solar systems with photovoltaic PV panels

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Abstract. For the production of electricity from renewable sources with photovoltaic (PV) systems, lately, technical solutions have been developed for both domestic and non-domestic customers. Regardless of the photovoltaic systems type (connected directly to the power grid, with the storage of energy produced in batteries or hybrids), the efficiency of the system is affected by both PV performance and losses during photovoltaic energy conversion or power grid delivery. In this regard, the article analyses the causes that affect the PV systems efficiency and proposes reduction methods. Also, the effects of average humidity and maximum wind speed on PV performance are discussed. The purpose of this study is to optimize photovoltaic systems by proposing solutions to minimize losses of any kind.

1. Introduction

Renewable Energy Sources (RES) contribute to mitigating climate change by reducing greenhouse gas emissions, thereby achieving environmental protection in the concept of sustainable development [1]. As a result of awareness of the factors that negatively affect the environment, photovoltaic systems have emerged as a direct necessity, and have witnessed a wide RES spread for the electricity production in the last period. Globally, energy demand is expected to grow up to 32 percent by 2040, so energy-efficient solutions are extremely important [2].

According to the trends imposed and encouraged by EU policies, the level of RES penetration is steadily increasing. Regarding energy, for the years 2020, 2030 and 2050, the EU has set the following objectives [3]:

2020 targets:
- 20% of energy from renewable sources;
- 20% increase in energy efficiency;

2030 targets:
- at least 27% of EU energy will be produced from renewable sources;
- energy efficiency increase by 27-30%;
- reaching an electrical interconnection level of 15% (more precisely, 15% of the electricity produced in an EU country could be transported to other Member States);

2050 targets:

- 80-95% reduction in greenhouse gas emissions compared to 1990 levels.

As far as the 2030 targets are concerned, particular attention should be paid to the problems of integrating these sources with a variable potential. In order to ensure an increase in the share of energy from RES that leads to a 75% share of gross final energy consumption in 2050 and 97% of electricity consumption, major investments in energy infrastructure are required [4]. Investing in energy requires time to produce results. In this respect, the infrastructure built years ago needs to be strengthened. To improve the efficiency of RES-based technologies and to obtain competitive costs, an improved infrastructure for integration across Europe is needed. With sufficient capacity and smart grid, the management of RES variations in certain areas can be solved by interconnecting the European Union national energy systems [4].

Therefore, in the future, with the increase in the share of energy in RES, emphasis should be placed on the evolution of production technologies. In this respect, investing in new technologies and improving existing ones is absolutely necessary.

In terms of photovoltaic technology, improvements in the performance of photovoltaic panels are needed to get more energy and minimize the causes that affect the efficiency of photovoltaic systems.

2. Integration of photovoltaic systems in the NES of EU countries

The competitiveness of systems used to produce electricity based on renewable energy is characterized by the key factor - the price of one kilowatt-hour produced. The productivity of systems using renewable sources depends fundamentally on natural conditions, so for these plants what matters is the generated power rather than the installed power.

For the interconnection of RES into NES, it is needed an analysis to target:

- the possibility of connecting a new energy objective to the National Energy Systems (NES) based on stationary regimes (adherence to the admissible voltage bands), verification of the loading of the existing electric networks in the area, verification of sizing criteria, determination of losses, static stability and short-circuit currents;
- evaluating operating conditions over a one-year period, analysing the power generated instantly according to forecasts made over short intervals;
- analysing the conditions for the power network operation after connecting the new energy objectives and studying the power network area where a new energy objective was connected.

The interconnection of RES in the energy system from the point of view of transmission and distribution operators has determined:

- the requirement to strengthen the infrastructure
- difficulties in production / consumption balancing, requiring the productive capacities discontinuation;
- the difficulty of achieving cross-border export;
- the need to create a power reserve for rapid production / consumption swing as a result of the photovoltaic systems random operation [5], [6].;
- informing producers of the current need to acquire the fast tertiary reserve used to balance the sudden variation in photovoltaic power.

The criterion for determining the RES maximum capacity that can be integrated into NES is the rapid tertiary reserve value available in existing national electrical power networks. This value is determined by the photovoltaic plants maximum capacity estimated to be disconnected to compensate for the available tertiary reserve load / discharge [7].

3. Factors that influence the photovoltaic systems efficiency

As far as the design of photovoltaic systems is concerned, it is necessary to consider all the factors that influence their energy efficiency. Due to the photovoltaic cells energy consumption,

photovoltaic systems have a very low efficiency factor, so that it may have, in the best case, the value of 6 [8].
The factors that affect the photovoltaic systems performance are:

- meteorological factors: solar radiation, ambient temperature, wind speed and precipitation;
- location factors: orientation and inclination, solar generator shading, pollution degree, local reflections and dirtiness degree;
- factors at conversion system level: adaptation losses to load, storage system losses, losses at power conditioning system, Joule losses/voltage drops, relation between energy production-consumption curve- storage capacity (possibility);
- the FR performance factor which is determined with the relation:

$$FR = \frac{E_{AC}}{\eta_{STC} \cdot E_{GS}} \cdot 100\% \tag{1}$$

where: E_{AC} - energy to consumer (inverter output) [kWh];
E_{GS} - solar energy in the capture plan [kWh];
η_{STC} - modules efficiency under standard test conditions.

Among the factors that influence the photovoltaic system efficiency, listed above, we have addressed the shading effects, panel temperature, cable thickness, solar cell characteristics, inverter efficiency, charging controllers, storage systems, and last but not least dirtiness degree and maintenance state. To reduce these effects, several possible solutions have been proposed.

3.1. Temperature

Photovoltaic panels testing can be done either under standard test conditions (STC) or under test conditions to measure solar panel performance under real conditions (PTC). The primary difference between the two test conditions STC and PTC is the temperature. Table 1 shows the values for the two test conditions [9]. For photovoltaic modules the test conditions are set by the standards: IEC 61215, IEC 61646 and IEC 62108.

Table 1. Test conditions.

Conditions	STC	PTC
Solar cell temperature	77°F (25°C)	113°F (45°C)
Ambient temperature	77°F (25°C)	68°F (20°C)
“Cooling” wind speed	None	2.2 mph (1 m/s)

Panel heating above the test temperature has effects on the output voltage that drops with 0.25% for amorphous cells and about 0.4-0.5% for crystalline cells, which causes a decrease in panel power. Thus, in hot summer days when demand for energy is high (supply of air conditioning systems, etc.), the power generated by photovoltaic systems is considerably reduced.
Real operating conditions are substantially different from laboratory testing, which is why it is necessary for all manufacturers to specify the photovoltaic cells nominal operating temperature (important parameter for panel selection) and test temperature.

3.2. Shading

From the shading point of view, it would be ideal to place the panels so that they are never shadows on them because shaded cells affect the entire panel current flow of. Generally, the panels are wired in series and a shaded panel will affect the power of the entire plant. For this reason, this situation should be considered from the design stage.

An obvious solution is to avoid the panels to be serial wired, if possible, or at least the shaded ones. To avoid overheating the photovoltaic panel as a result of shading, in series with the panel / socket, a by-pass diode will be mounted to minimize the thermal effect of the short-circuit current due to the blurring. Generally, the panels are wired in series and a shaded panel will affect the entire plant power. For this reason, this situation needs to be analysed from the design stage.

3.3. Electrical cable section

The choice and checking of the electrical cables is done in accordance with NTE007/08/00 [10] based on a technical-economic analysis and must take into account:

- the nature of the current (AC-DC, single-phase, biphasic or three-phase);
- nominal voltage;
- maximum network operating voltage;
- over voltages;
- installed power;
- power factor;
- admissible voltage drops;
- short circuit check;
- the economic section;
- the laying mode (outdoor or not exposed to sunlight, buried);
- the thermal characteristics of the environment.

The section of conductors is determined as the largest (technical or economic) section resulting from the sizing and checking calculations for the maximum continuous current, short-circuit thermal stress and voltage drop. For outdoor-wired conductors, sun-exposed cables should be provided in areas exposed to sunlight.

4. Analysis of the photovoltaic system efficiency. Case Study.

In the article an analysis of a photovoltaic installation for a large electricity consuming economic operator located in Romania, Biled, is performed (Figure 1). The estimation of the potential photovoltaic installation performance was done by using the PVWatts® software [11].

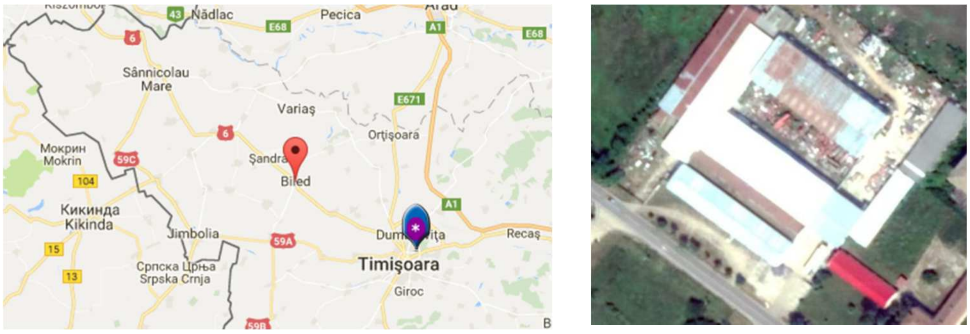

Figure 1. The analysed location.

Since the location has several areas where photovoltaic panels (terraced roof) can be located, several sets of simulations were made to determine the final solution. After analysing the results obtained in terms of the amount of energy produced by the system for different areas and versions of the location of the photovoltaic panels (with the possibility of orientation in the south direction) it was found that for the location of the photovoltaic system at the centre of the consumption weight, the lowest power losses were obtained (Figure 2).

Of course, this location opportunity is not generally valid depending on the location possibilities, which is why we consider necessary that the estimations of the energy production and the design of the photovoltaic systems to be made after the location possibilities evaluation.

In the following the optimal solution obtained from the simulation is presented, both in terms of location possibilities and the lowest loss of the system under real operating conditions.

Figure 2. Optimal location version.

In order to describe the weather conditions and renewable potential assessment, PVWatts® uses TMY2 weather files based on recent and accurate data, recommended by the National Renewable Energy Lab (NREL). PVWatts® Solar Power Data provides information on the solar radiation intensity and weather conditions (wind temperature and speed, geographic coordinates, altitude, etc.) for the site area. Site location information is shown in Table 2.

Table 2. Romania, biled 450 (location and station identification).

Requested location	Biled, Romania
Weather data source	Timisoara, Romania
Latitude	45.77° N
Longitude	21.25° E
Elevation	88

In this study, PVWatts® estimates the actual system capacity because it is not necessary to specify the roof slope and azimuth as it is a flat surface.

The photovoltaic modules selection was based on the analysis of the nominal module efficiency, the cell material and temperature coefficient. For the analysed modules the information is presented in Table 3. The module type determines how PVWatts® calculates the incidence and temperature correction factor for the optimal photovoltaic cell operation.

Table 3. Module Type Options.

Type	Approximate efficiency	Module cover temperature	Coefficient of power
Standard (crystalline silicon)	15%	Glass	-0.47 %/°C
Premium (crystalline silicon)	19%	Anti-reflective	-0.35 %/°C
Thin film	10%	Glass	-0.20 %/°C

Thin film modules were selected, tested according to the STC standard method, based on the best power coefficient value and not the average efficiency values because these are set under standard test conditions. Thus, when the modules are heated at 65°C during summer (temperature measured on a panel not installed within a few days in 2017) it is found that this modules type have the lowest output power loss (8°C when reaching a temperature of 65°C).

The photovoltaic system simulation was carried out by introducing photovoltaic system data based on the economic agent consumption. The program also allows to estimate the cost of energy produced by the system. The obtained results are centralized in Table 3.

The total loss calculated for the analysed photovoltaic system is of 14.08% and is due to the operating conditions presented in Table 4.

Table 4. Losses due to operating conditions.

Category	Default value (%)
Soiling	2
Shading	3
Snow	0
Mismatch	2
Wiring	2
Connections	0.5
Light-Induced Degradation	1.5
Nameplate Rating	1
Age (New equipment)	0
Availability	3

Degradation of the PV module produces progressive efficiency losses. Inverter efficiency has a default value of 96% - inverter conversion losses are not included in the system losses percentage. Temperature losses are calculated according to the temperature at the photovoltaic cells surface.

The photovoltaic system simulation was carried out by introducing photovoltaic system data based on the consumption of the economic agent. The program also allows you to estimate the cost of energy produced by the system. The results obtained are centralized in Table 5.

Table 5. Estimation of monthly electricity production.

Month	AC system output (kWh)	DC array output (kWh)	Solar radiation ($kWh/m^2/day$)	Plane of array irradiance (W/m^2)
1	10108.80	10737.44	1.66	51.56
2	14630.18	15399.22	2.65	74.30
3	23615.59	24755.69	3.88	120.15
4	28021.69	29331.47	4.83	144.82
5	35087.75	36689.51	5.91	183.33
6	37176.23	38844.77	6.57	196.96
7	39835.32	41612.14	6.84	212.04
8	36024.60	37644.14	6.17	191.41
9	27342.92	28612.47	4.78	143.26
10	22690.53	23759.42	3.80	117.71
11	11944.08	12621.34	2.04	61.32
12	8597.14	9176.60	1.42	43.92
TOTAL	**295074.83**	**309184.21**	**50.55**	**1540.78**

The average cost of purchased electricity is the retail price of electricity from your electricity service provider. The electricity generated by the projected photovoltaic system can be delivered to NES or can be consumed for its own services.

In order to measure the photovoltaic system performance, it was used as an indicator the capacity factor of 13.9%. Capacity factor is the unit ratio between the actual amount of electricity produced over a given period of time and the system installed power.

To evaluate the efficiency of the photovoltaic system, in Figure 3 is plotted for a period of 140 days, the power to the inverter input/output terminals depending on irradiance and respectively, irradiance at the photovoltaic panels surface. Also, the temperature at the photovoltaic panels surface was plotted to highlight whether there were changes in the photovoltaic panels power.

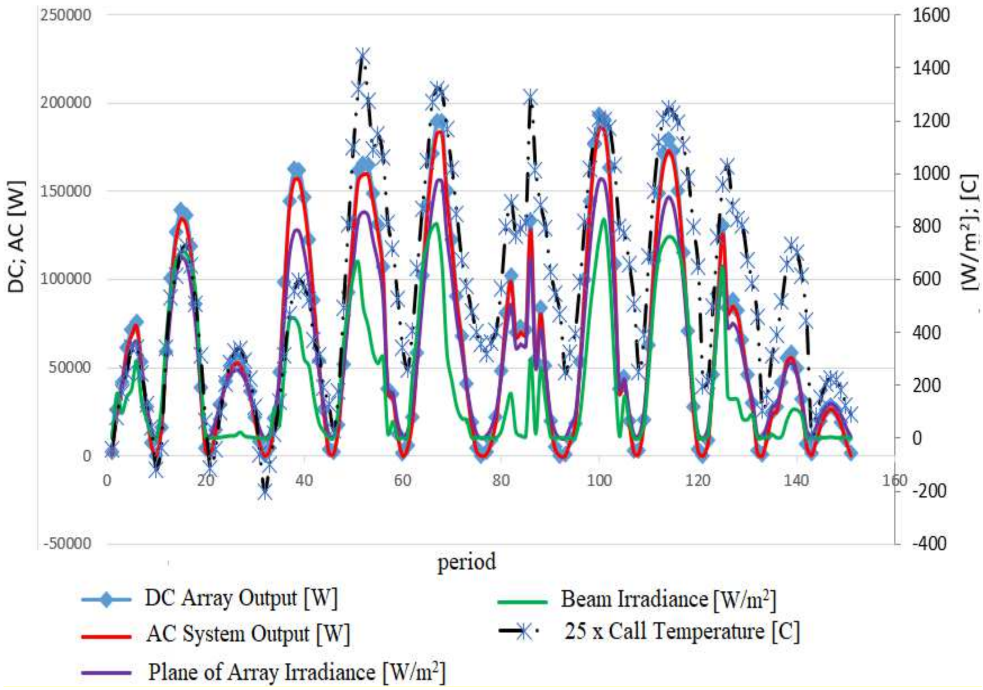

Figure 3. Power variation depending on irradiance.

Following the interpretation of the graph shown in Fig. 3 it can be noticed that the variation of the power to be charged by the photovoltaic system has the same irradiance at the surface of the photovoltaic panel.

It can be noticed that within the time intervals in which the temperature at the panels surface increases, the power dissipated by the photovoltaic system decreases considerably, diminishing the photovoltaic system efficiency.

As a measure to reduce the losses that influence the decrease of PV system efficiency, the following solutions are proposed:

- water / air cooling systems of PV panels at temperature elevation at the surface of PV panels when the test temperature is exceeded;
- closed loop installations for PV modules periodic washing.

5. Conclusion

Like other types of systems (wind, nuclear, or cogeneration), photovoltaic systems do not have the capacity to vary their output according to consumer demand, which makes impossible to cover the consumption curve. Another problem of photovoltaic panels is the efficiency of transforming solar energy into electricity. Also, important energy losses can be attributed to weather conditions -conditions that can be estimated but cannot be known for certain in the design phase - and dust/snow deposits on the PV capture surface. To the decrease in efficiency of electric power production also significantly contributes the increase of the temperature at the PV panels surface, but also the cables and related electrical equipment. By completing the PV systems with cooling and washing facilities, energy losses can be considerably reduced, with favourable effects on the PV systems efficiency.

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