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Technical performance analysis of a 40 kW photovoltaic installation

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To reduce the consumption of classically produced electric energy, which is an important green gas pollution factor, various renewable energy sources are now implemented on larger and larger scale. Both industrial and household consumers make use of such renewable energy sources. This work presents the characteristics and performance of a 40 kW photovoltaic installation mounted on the roof of an industrial production hall. The design and the implementation of the photovoltaic installation allows it to function while connected to the local power grid. On-site measurements have shown that the installation ensures symmetric voltages and currents, functioning at the planned parameters.

Keywords: *Photovoltaic installation, technical performances, measurements, efficiency, harmonics*

1. Introduction

Following the European directives [1] until 2020, 20% of the consumed energy in the European Union must come from renewable sources, with 10% used by the transport industry. By 2030, the current European directives [2] indicate that the at least 27% of the consumed energy must originate from renewable resources, with the goal of increasing this percentage to 32%.

Motivated by the mentioned European directives, quite a considerable number of projects have been started that focus on producing energy from renewable sources (solar, wind, hydraulic), with more and more certified energy producers. Thus, at the end of 2019, the National Energy Regulatory Authority (ANRE)[1] certified 573 economic entities with 635 energy production units in photovoltaic power

[1] Acronyms reflect the Romanian denominations.

plants. The installed capacity for these photovoltaic power plants is between 0,002 MW and 56.112 MW, while the total installed power was of 1.258.434 MW [3].

On September 5, 2020, at 1pm, we saw a record of photovoltaic energy produced by installations connected to the National Energetic System (SEN), the generated power of 774 MW representing 9,9% of the totally produced power in Romania at that time [4].

Figure 1 presents the energy production and consumption curves for a three-day period, from September 4 to September 6, 2020, where the maximum of electrical power produced by photovoltaic power plants can be observed.

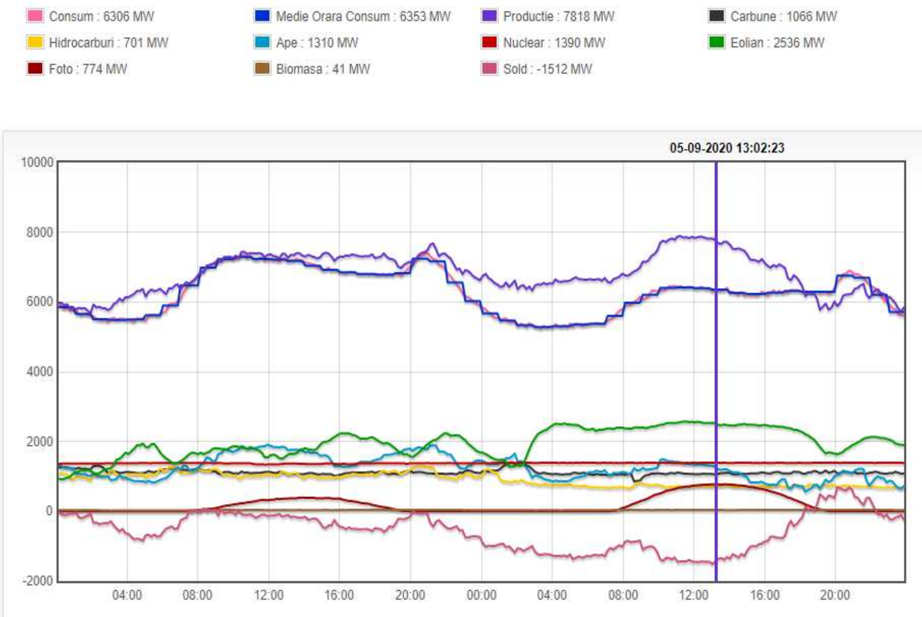

Figure 1. Electricity production and consumption curves [4]

We find in the literature various studies and applications where photovoltaic installations are used to power various consumers, including industrial and transportation consumers [5-9].

Various operational programs and funding granted by the Romanian Ministry of Environment support companies and individuals in their efforts to invest in the production of photovoltaic energy. In this context larger numbers of investors and individuals have assembled such photovoltaic installations and mounted them on buildings, becoming energy producers, either connected to the National Energetic System or operating in islands.

In this work we present our analysis of a 40 kW photovoltaic power plant. We look at the voltage and current waveforms, at the harmonic and distortion levels, and at the installation's capacity to supply the necessary energy.

2. Technical Details of the Studied Photovoltaic Installation

The 40 kW photovoltaic plant we analyse in this work has 160 photovoltaic panels of 270 W, two invertors, a Smart Power Sensor, measurement instruments, connecting appliances, and protective installations.

The photovoltaic installation schema the most important element is the MPPT solar controller (Maximum Power Point Tracking) which plays a critical role in obtaining the maximum power out of the solar energy, and the efficient use of the panels.

The technical characteristics of the photovoltaic panel are presented in [10].

Figure 2 presents the current variation curves depending on voltages, for the various incident radiations. The figure also marks the maximum power values P_{mpp}.

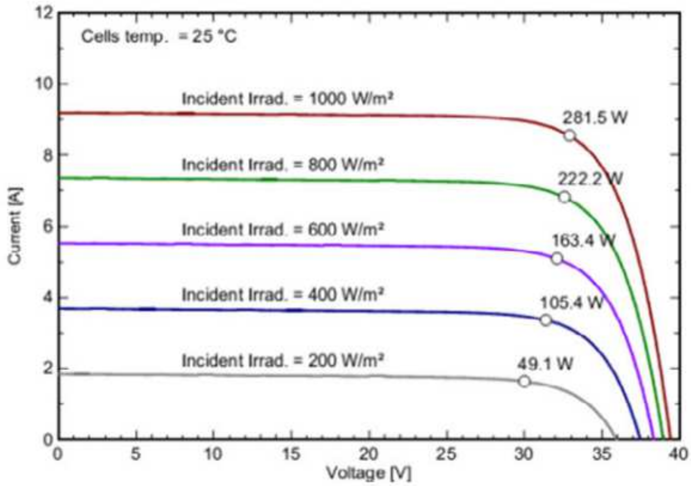

Figure 2. Current-Voltage variation curves [10].

Further, for the same 1,000 W/m^2 incident radiation, we find different maximum power values, depending on the photovoltaic cell temperatures (Figure 3). We see that the optimal cell temperature should be of 25℃, which requires a cell cooling installation in the days with high temperatures.

The 160 panels installed on an industrial hall roof are divided into two groups, 80 for each invertor. In turn, the 80 panels in each group are arranged into four rows of 20 panels. The 8 ends of the rows are connected with safeties to a direct current box switch.

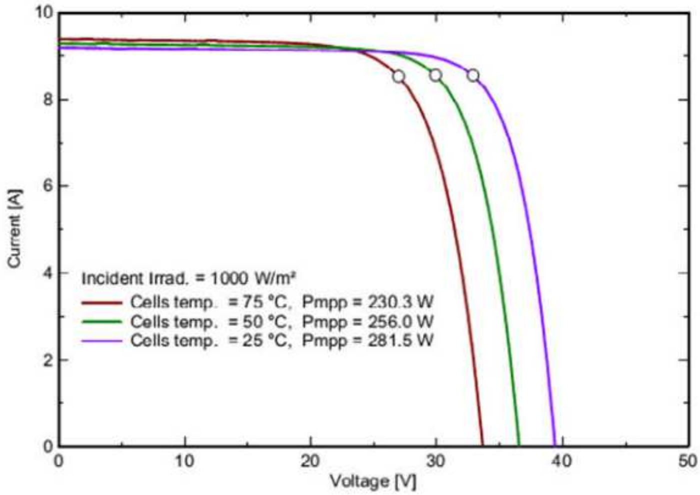

Figure 3. Current-Voltage curves for different photovoltaic cell temperature values [10].

The main technical parameters of the analysed invertors are presented in [11].

We present in Figure 4 the connection schema for the two invertors, connection that is realised by self-synchronisation.

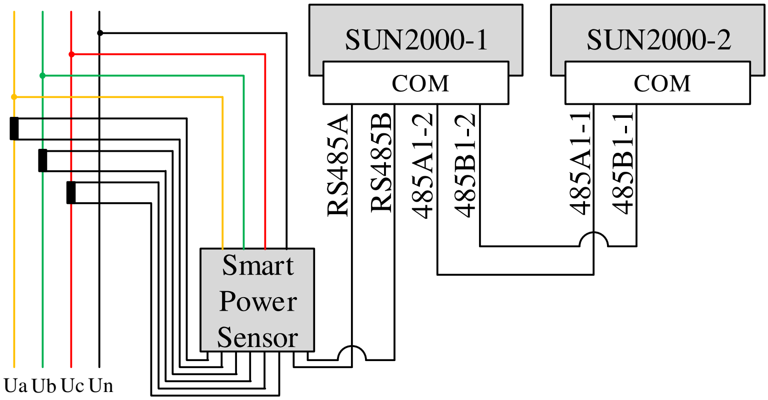

Figure 4. Invertor connection to the grid schema

The schema in Figure 4 makes clear that the invertors can only connect to the power grid when the Smart Power Sensor detects the grid voltage and sends impulses to synchronize the invertors with the power network. This is advantageous to the installation as it allows the photovoltaic installation to avoid an insular functioning as well as eliminating the possibility of supplying with energy appliances that do not belong to the installation's owner.

3. Testing the Photovoltaic Installation

We describe here the measurements taken during February 2020, after 15:00 when the illumination levels were above 20.000 lx. We measured surface luminancies, obtaining the following values:

- L_s = 3.200 cd/m^2, at ground level, on light grey pavels;
- L_{th} = 2.554 cd/m^2, on the industrial hall metal sheet, with a shiny light grey coating;
- L_{ta} = 906,6 cd/m^2, on the blue metal sheet adjacent to the photovoltaic panel;
- L_{PV} = 697,4 cd/m^2, on the panel's dark surface.

Considering that the incident radiation on the photovoltaic panels has the same values as on the ground level, we obtain the panels' reflection coefficient, k_r:

$$k_r = \frac{L_s - L_{PV}}{L_s} \cdot 100 \quad [\%] \tag{1}$$

That is:

$$k_r = \frac{3200 - 698}{3200} \cdot 100 \cong 78 \quad [\%] \tag{2}$$

The panels' absorption coefficient, k_a, for the time of the measurements was:

$$k_a = 1 - k_r = 22 \quad [\%] \tag{3}$$

We also measured:

- The power supplied by the photovoltaic power plant (Figure 5): 14,25 kW;
- The reactive power: 0,13 kVAR;
- The apparent output: 14,25 kVA;
- The power factor: 1;
- Frequency: 50,01 Hz.
- The circuit voltages supplied by the installation's inverters, connected to the power grid, have almost the same values, and have a sinusoidal shape (Figure 6);
- The currents on the three phases, from the inverter to the network are almost equal in values, and have a sinusoidal shape (Figure 7);
- The Total Harmonic Distortions of each phase's currents and voltages (Figure 8).

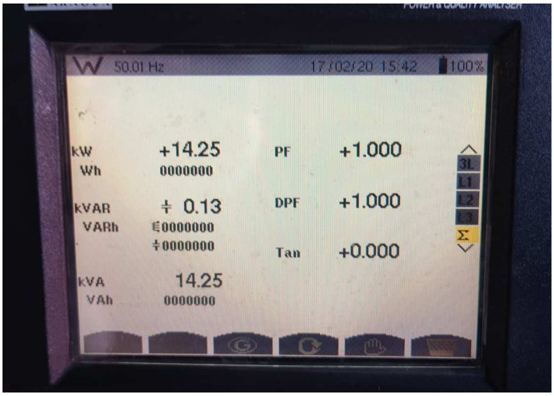

Figure 5. Measured power and power factor values for the photovoltaic installation

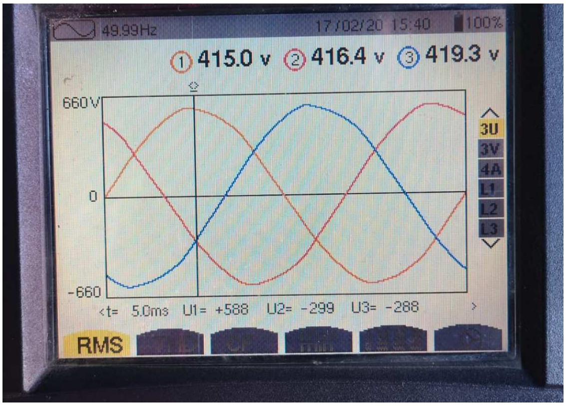

Figure 6. Circuit voltages for the photovoltaic installation

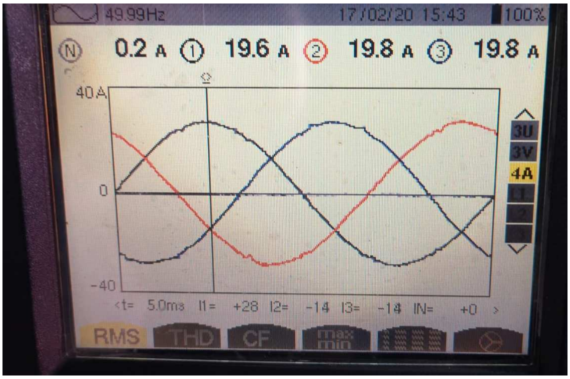

Figure 7. Current values on the three phases

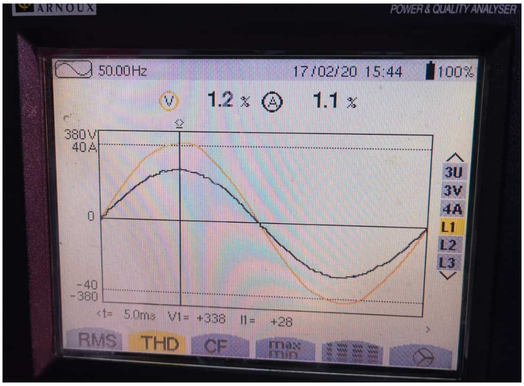

Figure 8. Voltage and Current superior harmonics

4. Conclusion

Although the solar radiation did not have maximum values during the measurement taking, the power supplied by the photovoltaic installation represented 35,63%. The current and voltage wave shapes are very close to a sinusoidal shape, the amount of superior harmonics being very low (1,2%):

The panels' positioning angle is of 10% to the ground, which is too low. We recommend, therefore, that the panels are position at an approximately 35º from the horizontal. For an increased efficiency, we see the need of a sun tracking system. Furthermore, to allow the use of the produced energy also during the night, it is needed to install a batteries storage system.

As the consumer's installed capacity is of 140 kW while the photovoltaic installation supplied power is of 40 kW, the photovoltaic panels can only ensure a 28,7% of the necessary electric energy. The company that has installed the photovoltaic panels, however, owns three further industrial halls, on each of which further photovoltaic panels are to be installed. If this happens, the consumer will become energy independent, as the installed capacity of the enlarged photovoltaic system will surpass the consumer's installed power.

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