# MATLAB Simulation of Grid-Connected Photovoltaic System

Pande Popovski[1], Natasa Mojsoska[2] and Blagoja Stevanoski[2]

*Abstract* – **In this paper work will be briefly covered the principle of operation of photovoltaic system, the procedure of integration of such power plants in the power system, their impact on the system and the technical norms that they should meet. Furthermore, the numerical results obtained from the simulation of a photovoltaic system conducted in Simulink will be shown and commented on. Along with this, the model with which the simulation was made, which was made on the basis of a real photovoltaic system owned by the Technical Faculty - Bitola, will be discussed.**

*Keywords* – **Photovoltaic system, Matlab/Simulink simulation, Renewable energy sources RES.**

## I. Introduction

In the last few decades, especially since the beginning of the 21st century, the interest in the participation of renewable energy sources (RES) as producers in the power system has been progressively increasing. One of the reasons for this is the continuous increase in consumption, both in developing countries and in already developed countries. Global warming has also contributed to this, which has become a major topic of interest due to its close connection to the use of fossil fuels [1].

Among other types of renewable sources is the energy obtained from photovoltaic power plants, which is marked by the highest increase from the others. In 2002, an average annual increase of 48% was recorded, and by the end of 2008 the total installed capacity of such power plants in the world exceeded 16 GW [2]. A report by the European Photovoltaic Industry Association (EPIA) shows that in 2010 the total installed capacity of photovoltaic power plants in Europe was 29,777 MW, while in 2019 in the European Union this power was 130GW. In whole world in 2019 installed capacity of photovoltaic power energy was 585GW.

### A. Standards

The organizations in charge of normalization in photovoltaic systems are IEC and IEEE - SA.

[1]Pande Popovski is postgraduate student at Technical Faculty - Bitola, Makedonska falanga 33, 7000 Bitola, E-mail: popovski.pande@gmail.com

[2]Natasa Mojsoska is with University of Sv. Klimenit Ohridski – Bitola, Technical Faculty - Bitola, Makedonska falanga 33, 7000 Bitola, E-mail: natasa.mojsoska@tfb.uklo.edu.mk

[2]Blagoja Stavanoski is with University of Sv. Klimenit Ohridski – Bitola, Technical Faculty - Bitola, Makedonska falanga 33, 7000 Bitola, E-mail: blagoj.stavanovski@uklo.edu.mk

The key standards in the field of IEC photovoltaic systems are:

• IEC 61730 Photovoltaic Safety Module

• IEC 61215 Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval

• IEC 61646 Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval

The IEC 61730 standard covers thorough structural requirements in order to ensure mechanical safety as well as reliability in the operation of photovoltaic systems during their lifetime. This standard in combination with the IEC 61215 or IEC 61646 standard practically covers the thorough construction of photovoltaic modules.

The IEEE - SA standards for photovoltaic systems are:

• IEEE 1262 Recommended Practice for Qualification of Photovoltaic (PV) Modules

• IEEE 1374 Guide for Terrestrial Photovoltaic Power System Safety

• IEEE 928 Recommended Criteria for Terrestrial Photovoltaic Power Systems.

There are organizations that are committed to developing and coordinating standards. The most important of these are the following organizations:

• ISO (International Organization for Standardization) is an organization composed of 145 national institutions and 193 technical boards, and is the most important organization for development and standardization.

• IEC (International Electrotechnical Commission) is a leading organization for the development and adoption of norms in the field of electrical engineering. It consists of 112 technical boards.

• CEN (Comité Européen de Normalisation) is the European Normalization Organization, while CENELEC (European Committee for Electrotechnical Standardization) is the European Organization for Normation in the field of electrical engineering.

### B. Procedures for Development and Construction of Power Plants from Renewable Energy Sources

In the Republic of North Macedonia, for the implementation of projects for renewable energy sources, more specifically photovoltaic power plants, relevant legal and regulatory acts have been established. [6] provides detailed guidelines for investors planning to enter the market as electrical energy producers from renewable energy sources. The following steps, procedures, and required documentation are generally included in this process:

• Establishing a company

• Land use

978-1-7281-7142-5/20/$31.00 ©2020 IEEE

• Environmental Impact Assessment Study
• Consent for connection to the distribution system
• Building permit
• Gaining temporary status of preferential producer
• Design and construction of the connector
• Approval for use
• License to produce electrical energy
• Registration of the object in the register of objects for production of electrical energy from renewable energy sources:
• Awarding the status of preferential producer
• Electrical energy purchase agreement with electrical energy market operator

## II. MATLAB SIMULATION OF GRID CONNECTED PV SYSTEM

An analysis of the performance of a photovoltaic power system through simulation using Simulink - a graphically oriented program tool based on Matlab - will be explained. The structure of the model to be used for the simulation and how it works will be explained. The used model is based on an already existing photovoltaic system that is installed on the roof at the Technical Faculty - Bitola, and is connected on the distribution network.

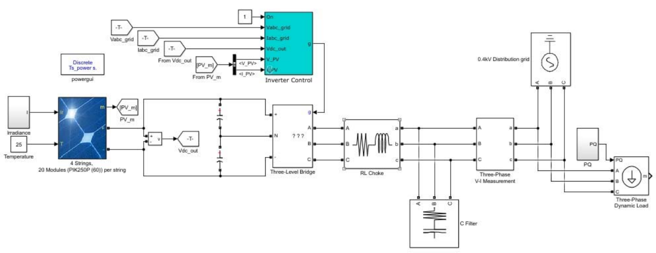

Fig. 1. Model for a photovoltaic plant built in Simulink

An existing database on solar radiation in the area where the plant is installed will be used for the assessment of the energy potential of the PV system, as well as for the consumption of the Technical Faculty - Bitola for two characteristic days. With the help of the model, the produced electrical energy will be calculated in such conditions. The results will be compared with those obtained in the conceptual design made for the existing power system.

### *A. Model of the Photovoltaic System*

Two PV systems with a power of 10 kW or a total of 20 kW are installed on the roof of the Technical Faculty in Bitola. The real photovoltaic system for which the model is made in Simulink is composed of a structure with solar modules made of polycrystalline silicon with a power of 250W. The modules are grouped into four arrays, where each array has 20 serial-connected modules. The four arrays via a DC switchboard with single-pole fuses and surge arresters are connected to separate inputs from a three-phase inverter. Compliance of the voltage and current levels of the inverter with the voltages of the series solar modules has been made taking into account the dependence of the voltage of the solar modules on the temperature. That temperature range ranges from -10°C to 70°C. The inverter has a rated power of 20kW, and has MPPT capability. Furthermore, the inverter with the main switchboard is connected via a three-pole switch.

Simulink is a graphically oriented tool that can use blocks to construct and simulate a particular system. The tool contains a wide library, which also contains a package of blocks designed to simulate power systems. Using the required blocks, the model shown in Fig. 1 is constructed.

In addition to the model of the photovoltaic power plant, oscilloscopes, along with other additional blocks, have been installed to carry out the necessary measurements. In general, solar radiation is measured at one of the block inputs for solar modules, the effective values of the phase voltages and currents at the output of the power system connected to the network, as well as the active power at the output of the PV system. Also, the output power is sampled at certain time intervals in order to be further used to calculate the produced electrical energy. The measurements were made with the help of a measuring block that provides data on the voltages and currents at the output of the system.

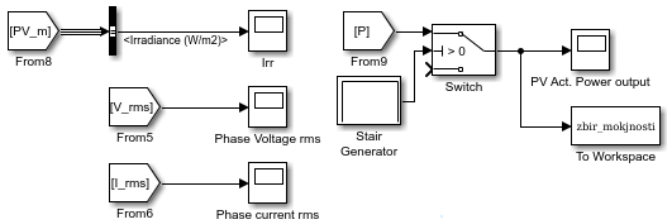


Fig. 2. Instruments for conducting the necessary measurements

In order to measure the effective values of current and voltage as well as the active power transmitted by the PV system, it is necessary to divide the voltages and currents from the measuring block into a module and an argument. The modules are then divided by √2 to obtain the effective values. Ultimately, the active power is calculated using the obtained quantities.

It can be seen from the Fig. 2 images of the instruments and blocks for the required calculations that the power factor is not taken into account in the calculation of active power, i.e. it is adopted to be 1, and the instrument for measuring active power is used a switching block that misses the active power signal after a certain time. This is done in order to avoid inaccuracies in the results due to the occurrence of oscillations in voltage, current, as well as the phase shift in them at the moment of connection of the PV system to the network. This is a transient phenomenon that lasts for a fraction of a second, but due to the short time of the software simulation, these phenomena last relatively long and can lead to large errors in the results.

### *B. Used Data to Perform the Simulation*

A database of two characteristic days was used to perform the simulation. Specifically, the solar radiation in the area of the Technical Faculty was measured, as well as its consumption for one working day (24.01.2020) and one non-working day (16.02.2020). The measurements were made at a time interval of 15 minutes.

The data obtained are implemented in the model shown earlier. Two different models have been used that use the data from both days.

In the function, the collected data for the whole day are entered for a time interval of 0.96 seconds in order to shorten the simulation time. This means that in the simulation one hour is represented by a time interval of 0.04 seconds, and 15 minutes by a time interval of 0.01 second. This data is important for the calculation of the produced energy after the simulation is performed. The resulting solar radiation diagrams are shown in the figures below Fig. 3 and 4.

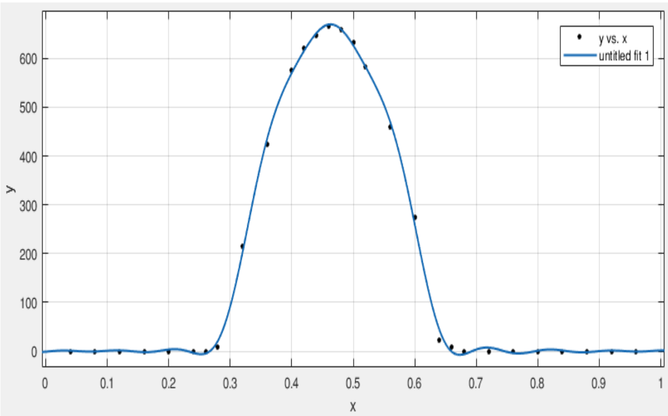


Fig. 3. Diagram obtained for solar radiation on 16.02.2020

The resulting algebraic expressions for radiation dependence and time consumption are implemented in Simulink through a block that connects a function written in Matlab to the model in which that block is placed. The inputs of this block are the coefficients generated by the tool shown in the pictures before, and also the block that gives the output time of the simulation at a given moment. The output of the solar radiation is connected to one of the inputs of the module, and the consumption block dictates the operation of a three-phase dynamic load, which represents the TFB.

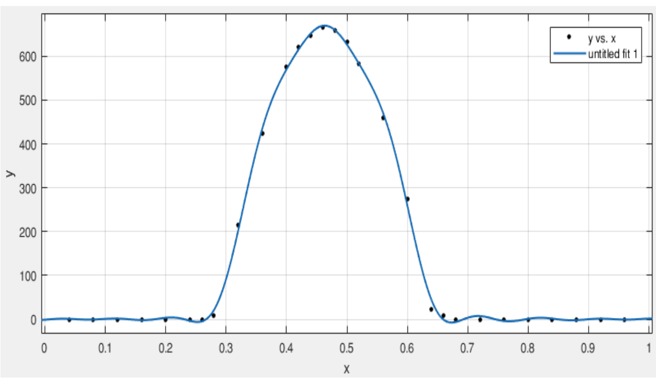


Fig. 4. Diagram obtained for solar radiation on 24.01.2020

## III. Analysis Results

After the simulation is released, the oscilloscopes draw the curves of the production of the photovoltaic system and the consumption of the faculty. Also, as mentioned in the 0.01 second time interval, the values of the power generated by PV system in Matlab's desktop are preserved. This data can be used to calculate the energy produced for both days.

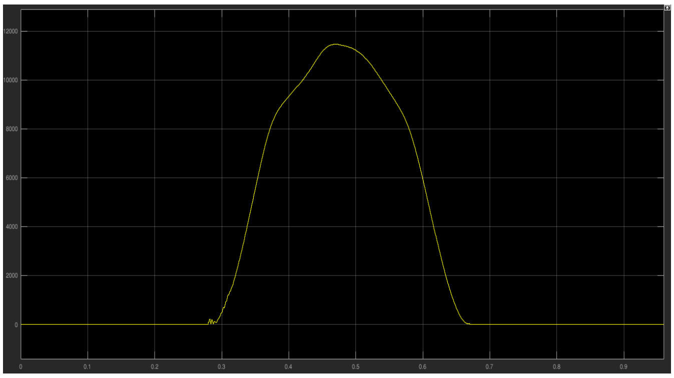

Fig. 5. Production on 24.01.2020

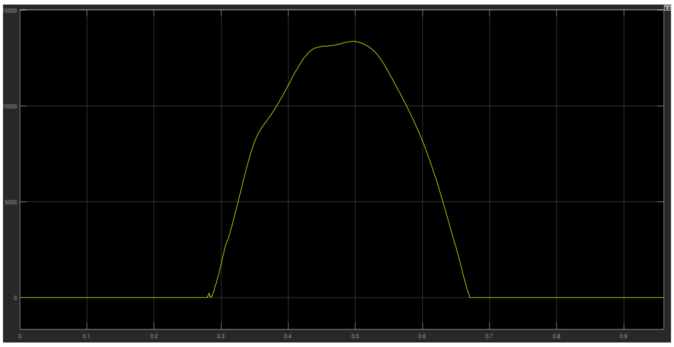

Fig. 6. Production on 16.02.2020

Fig. 5 and 6 shows the power output by the photovoltaic system for days 24.01 and 16.02.2020 obtained from the oscilloscope.

The results obtained for the energy produced for the two days are shown in Tables I and II.

If we compare the quantities of electrical energy produced by the simulation with the actual read values, we get the following:

On January 24, 2020, the photovoltaic system produced 71.47 kWh, and according to the simulation, we get produced energy 67.52 kWh, which is 3.95 kWh, or 5.5% less value than the real one. On February 16, 2020, the system produced 91.91 kWh, while the simulation results show a value of 86.76 kWh, or 5.15 kWh (5.6%) less than the real value.

In general, the model gives lower values for the produced power than the real ones. This may be due to the short simulation time, where transient phenomena occurring as a problem that result in an error in the results. If this is the case, the solution would be to increase the simulation time so that these oscillations have less effect. However, the bad side of this would be the long duration of the simulation.

TABLE I
SIMULATION RESULTS FOR THE DAY 24.01.2020

| Time | Production (kW) | Time | Production (kW) |
|---|---|---|---|
| 00:15 | 0.000 | 12:15 | 11.342 |
| 00:30 | 0.000 | 12:30 | 11.217 |
| 00:45 | 0.000 | 12:45 | 11.013 |
| 01:00 | 0.000 | 13:00 | 10.713 |
| 01:15 | 0.000 | 13:15 | 10.331 |
| 01:30 | 0.000 | 13:30 | 9.921 |
| 01:45 | 0.000 | 13:45 | 9.498 |
| 02:00 | 0.000 | 14:00 | 9.072 |
| 02:15 | 0.000 | 14:15 | 8.596 |
| 02:30 | 0.000 | 14:30 | 7.948 |
| 02:45 | 0.000 | 14:45 | 7.046 |
| 03:00 | 0.000 | 15:00 | 5.935 |
| 03:15 | 0.000 | 15:15 | 4.733 |
| 03:30 | 0.000 | 15:30 | 3.530 |
| 03:45 | 0.000 | 15:45 | 2.401 |
| 04:00 | 0.000 | 16:00 | 1.422 |
| 04:15 | 0.000 | 16:15 | 0.654 |
| 04:30 | 0.000 | 16:30 | 0.154 |
| 04:45 | 0.000 | 16:45 | 0.000 |
| 05:00 | 0.000 | 17:00 | 0.000 |
| 05:15 | 0.000 | 17:15 | 0.000 |
| 05:30 | 0.000 | 17:30 | 0.000 |
| 05:45 | 0.000 | 17:45 | 0.000 |
| 06:00 | 0.000 | 18:00 | 0.000 |
| 06:15 | 0.000 | 18:15 | 0.000 |
| 06:30 | 0.000 | 18:30 | 0.000 |
| 06:45 | 0.000 | 18:45 | 0.000 |
| 07:00 | 0.089 | 19:00 | 0.000 |
| 07:15 | 0.106 | 19:15 | 0.000 |
| 07:30 | 0.478 | 19:30 | 0.000 |
| 07:45 | 1.219 | 19:45 | 0.000 |
| 08:00 | 1.977 | 20:00 | 0.000 |
| 08:15 | 3.060 | 20:15 | 0.000 |
| 08:30 | 4.295 | 20:30 | 0.000 |
| 08:45 | 5.568 | 20:45 | 0.000 |
| 09:00 | 6.801 | 21:00 | 0.000 |
| 09:15 | 7.845 | 21:15 | 0.000 |
| 09:30 | 8.561 | 21:30 | 0.000 |
| 09:45 | 8.997 | 21:45 | 0.000 |
| 10:00 | 9.331 | 22:00 | 0.000 |
| 10:15 | 9.651 | 22:15 | 0.000 |
| 10:30 | 9.986 | 22:30 | 0.000 |
| 10:45 | 10.360 | 22:45 | 0.000 |
| 11:00 | 10.784 | 23:00 | 0.000 |
| 11:15 | 11.169 | 23:15 | 0.000 |
| 11:30 | 11.406 | 23:30 | 0.000 |
| 11:45 | 11.464 | 23:45 | 0.000 |
| 12:00 | 11.415 | 00:00 | 0.000 |

TABLE II
SIMULATION RESULTS FOR THE DAY 16.02.2020

| Time | Production (kW) | Time | Production (kW) |
|---|---|---|---|
| 00:15 | 0.000 | 12:15 | 13.359 |
| 00:30 | 0.000 | 12:30 | 13.368 |
| 00:45 | 0.000 | 12:45 | 13.274 |
| 01:00 | 0.000 | 13:00 | 13.082 |
| 01:15 | 0.000 | 13:15 | 12.772 |
| 01:30 | 0.000 | 13:30 | 12.316 |
| 01:45 | 0.000 | 13:45 | 11.724 |
| 02:00 | 0.000 | 14:00 | 11.079 |
| 02:15 | 0.000 | 14:15 | 10.423 |
| 02:30 | 0.000 | 14:30 | 9.730 |
| 02:45 | 0.000 | 14:45 | 8.989 |
| 03:00 | 0.000 | 15:00 | 8.176 |
| 03:15 | 0.000 | 15:15 | 7.241 |
| 03:30 | 0.000 | 15:30 | 6.180 |
| 03:45 | 0.000 | 15:45 | 5.014 |
| 04:00 | 0.000 | 16:00 | 3.782 |
| 04:15 | 0.000 | 16:15 | 2.575 |
| 04:30 | 0.000 | 16:30 | 1.248 |
| 04:45 | 0.000 | 16:45 | 0.000 |
| 05:00 | 0.000 | 17:00 | 0.000 |
| 05:15 | 0.000 | 17:15 | 0.000 |
| 05:30 | 0.000 | 17:30 | 0.000 |
| 05:45 | 0.000 | 17:45 | 0.000 |
| 06:00 | 0.000 | 18:00 | 0.000 |
| 06:15 | 0.000 | 18:15 | 0.000 |
| 06:30 | 0.000 | 18:30 | 0.000 |
| 06:45 | 0.000 | 18:45 | 0.000 |
| 07:00 | 0.089 | 19:00 | 0.000 |
| 07:15 | 0.464 | 19:15 | 0.000 |
| 07:30 | 1.709 | 19:30 | 0.000 |
| 07:45 | 3.039 | 19:45 | 0.000 |
| 08:00 | 4.304 | 20:00 | 0.000 |
| 08:15 | 5.699 | 20:15 | 0.000 |
| 08:30 | 7.070 | 20:30 | 0.000 |
| 08:45 | 8.162 | 20:45 | 0.000 |
| 09:00 | 8.846 | 21:00 | 0.000 |
| 09:15 | 9.333 | 21:15 | 0.000 |
| 09:30 | 9.853 | 21:30 | 0.000 |
| 09:45 | 10.443 | 21:45 | 0.000 |
| 10:00 | 11.086 | 22:00 | 0.000 |
| 10:15 | 11.748 | 22:15 | 0.000 |
| 10:30 | 12.349 | 22:30 | 0.000 |
| 10:45 | 12.791 | 22:45 | 0.000 |
| 11:00 | 13.030 | 23:00 | 0.000 |
| 11:15 | 13.111 | 23:15 | 0.000 |
| 11:30 | 13.137 | 23:30 | 0.000 |
| 11:45 | 13.184 | 23:45 | 0.000 |
| 12:00 | 13.273 | 00:00 | 0.000 |

Another cause could be the photovoltaic maximum power monitoring (MPPT) algorithm. The Perturb and Observe algorithm works by changing the voltage at the output of the photovoltaic, which measures the change in output power. With this method, the time interval controller increases the voltage as long as the measurements show that the power also increases. Working in this way can cause oscillations in voltage and current, and thus in output power. The solution to this would be to apply another more stable algorithm.

## IV. Conclusion

With the help of the Simulink software package, it is possible to create a very precise model of a photovoltaic power system. Simulink offers the user a wide range of databases and elements, and gives them complete freedom in analyzing such a model. For the same, it is possible to obtain relatively accurate production data, where the accuracy depends on the input data itself, as well as on how detailed the plant model is.

From the developed model it can be concluded that such an approach would be quite useful in the initial stages, i.e. when a PV power plant is in the design process. In this case, results would be obtained with satisfactory accuracy, which would give an idea of how much production capacity the plant will have. However, when it comes to more detailed analysis, such accuracy would not be sufficient. An example of this is the results of the simulation: for the days 24.01 and 16.02 an error was made in the energy production is around 5.5%, which although for one or two days is a relatively small error.

However, as mentioned, it is possible for the model to be improved and thus give more accurate results. Improving the model would be in the direction of how to increase the simulation time that Simulink will be able to do in a reasonable amount of time, which will probably improve the results.

## References


[1] E. Rakshani, K. Rouzbehi, A. J. Sánchez, A. C. Tobar, and E. Pouresmaeil, “Integration of Large Scale PV-Based Generation into Power Systems: A Survey”, 13 April, 2019.

[2] R. Goić, J. Krstulović Opara, I. Penović, D. Jakus, and I. Zlatunić, “Connection of Large PV Power Plant od Disstribution Network”, Umag, 16-19 May, 2010.

[3] B. Stevanovski, “Renewable Energy Sources RES”, Subject lectures, TFB Bitola, 2017.

[4] M. Atanasovski, “New Methods for Distribution of Losses in Distribution Networks with Dispersed Electricity Production”, PhD dissertation, FEIT Skopje, 2011.

[5] R. Orlovac, A. Tunjic, “Technical Requirements for Connection od PV Generators to the Public Low-Voltage Network”, CIRED, Šibenik, 18-21 May, 2008.

[6] “Guidelines on the Procedures for the Development and Construction of Power Plants Utilising Renewable Energy Sources – Photovoltaic Plants”, Project funded by EU, source: http://www.economy.gov.mk/Upload/Documents/Guidelines_on_photovoltaic_plants_B5_final_3.pdf