BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 62 (66), Numărul 3, 2016
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

SOME CONSIDERATIONS ON THE PHOTOVOLTAIC CONVERSION OF THE SOLAR ENERGY IN ROMANIA

BY

DRAGOŞ MACHIDON*, MARCEL ISTRATE and ROXANA OPREA

"Gheorghe Asachi" Technical University of Iaşi
Faculty of Electrical Engineering

Received: July 14, 2016
Accepted for publication: August 25, 2016

Abstract. The solar energy is nowadays one of the most exploited renewable resource, as both thermal and photovoltaic conversion are widely used from small domestic applications to significant power plants. This paper aims to present some aspects regarding the Romanian's national context in terms of photovoltaic conversion of the solar energy. In this rapidly evolving context, at the Power Engineering Department of the Electrical Engineering Faculty of Iasi, Romania, a small 4.32 kW photovoltaic power plant was developed for both didactical applications and electricity production. A detailed description of this photovoltaic power plant is also presented, along with some data on several study cases conducted.

Key words: solar energy; photovoltaic conversion; electricity.

1. Introduction

As the amount of the electrical energy consumed had doubled in the past two decades (Enerdata, 2016) it is obvious that conventional resources, namely fossil fuels, had to be exploited at a much higher rate in order to satisfy the demand of electricity. This increasing pressure had led to a growing concern regarding the fossil fuels depletion. Along with the significant environmental threats of the fossil fuels usage, the urge for finding and exploiting new energy sources appeared justified.

*Corresponding author: *e-mail*: machidon.dragos@tuiasi.ro

In this context, the renewable resources were obviously taken into account, and their exploitation has become a significant goal for countries all over the world. Nowadays along with the wind power, the solar power is one of the most exploited renewable resources, both in small scale domestic applications but also in large power plants. An eloquent example is that, only in the European Union (EU), the amount of electricity obtained from the solar energy increased from 0.4 TWh in 2003 to 85.3 TWh in 2013 (Eurostat, 2015).

This spectacular evolution was determined by the technological development, on the base of which more efficient solar conversion installations were realized and then became available at more attractive costs. Also, the renewable sector benefited from decisive political decisions, like the EU Commission's plan that, by the year of 2020, 20% of the total consumed energy should come from renewable sources (European Commission, 2009). Later on in 2014, the EU Commission has set a new target, of a minimum 27% share for renewable energy by 2030, thus setting assuring a favourable perspective for the renewable energy sector. (European Commission, 2014).

2. Solar Energy Development in Romania

As a European Union member, Romania had to implement a series of policies in order to achieve the target imposed by EU's Commission regarding the amount energy from renewable sources. Due to their significant potential, in Romania wind, hydro and solar energy types were taken into account as the main renewable resources.

Regarding the solar energy potential, Romania is placed in the European zone in category "B" (Barla *et all*, 2010), being ranked on the 11^{th} place in the 30 EU countries in terms of yearly irradiation from horizontal and optimum angle for vertical mounting (Banu *et all*, 2014).

The regions with the greatest solar potential are Dobrogea, Oltenia, Muntenia, and the South of Moldova, with values higher than 1350 kWh/year, as it can be seen from the Romania's Global Horizontal Irradiation (GHI) map presented in Fig. 1 (Solargis, 2017). Also, from Fig.1 it can be observed that basically more than a half of the Romania's surface has an average flux higher than 1250 kWh/m^2 (calculated for the time interval between 1994-2013).

On the base of this potential and considering the 2020 target set by the EU's Commission, Romanian government implemented an attractive support scheme mechanism in order to encourage the investments in developing renewable energy production capacities.

The legal frameworks for promoting the electricity from renewable energy sources were set through the Electricity Law (Parlamentul Romaniei, 2007), while the support scheme mechanisms were established through Law 220/2008 (Parlamentul Romaniei, 2008) and its subsequent modifications.

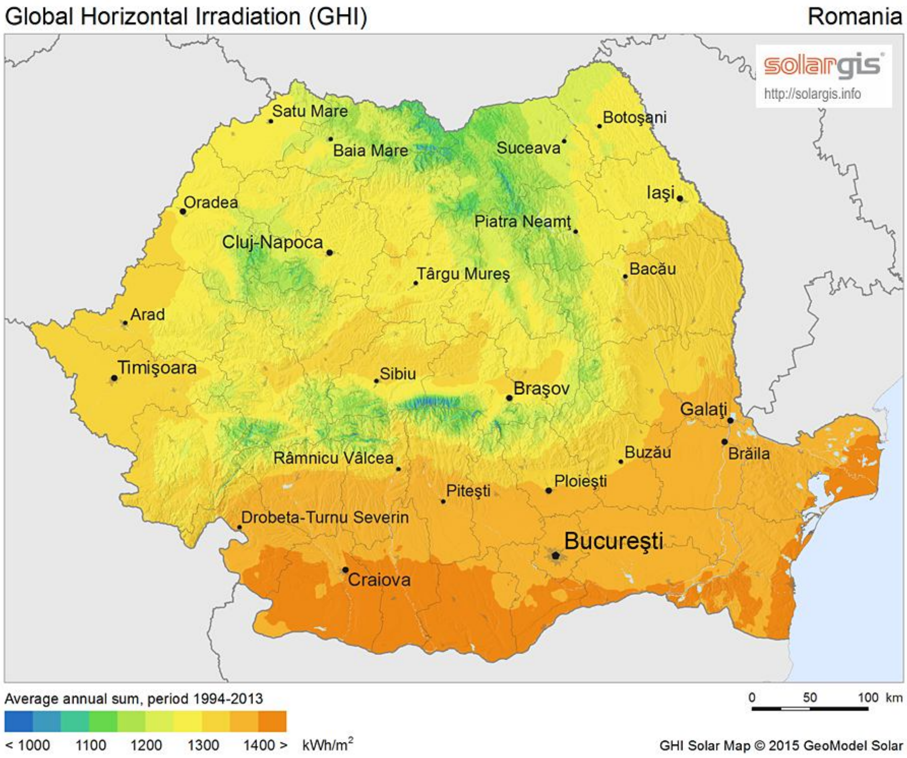

Fig. 1 – Romania's Global Horizontal Irradiation map.

Therefore, a system of Tradable Green Certificate was implemented, thus allocating a number of such Green Certificates (GC) per each MWh generated from renewable sources. The prices of these Green Certificates were regulated by the free market, although a minimum value of 27 €/certificate and maximum of 55 €/certificate was imposed by the law. These values are adjusted yearly on the base of average annual inflation rate.

Initially the photovoltaic energy was rewarded with a number of 6 Green Certificates per MWh, the highest number among all other renewable sources. Since 1st of January 2014, for new PV capacities the number of GC was reduced to 3 per produced MWh, while for the existent capacities a number of 2 GC was postponed and expected to be returned from April 2017 (Guvernul Romaniei, 2013). Also from April 2017 is expected that for one MWh of photovoltaic energy 6 GC will be rewarded once again. (ANRE, 2016)

As consequence, the installed photovoltaic capacities had grown from 1 MW installed in 2011 to 1300 MW installed at the end of 2015 (CNTEE Transelectrica S.A., 2017). In terms of electricity generation, at the end of 2015, almost 2 TWh were produced through photovoltaic conversion (Eurostat, 2016), which represents a share of approximately 3% of the total amount of generated electricity at the national level.

The development of this new type of power plants imposed significant changes to the national power system's structure and led to new challenges regarding the power system's operation. These challenges represent a great concern for academic and engineering areas all over the world.

In this context, a small 4.32 kW photovoltaic power plant was installed at the Electrical Engineering Faculty of Iasi, covering both didactic and practical purposes, as the installation is used for supplying with electricity different consumers from the Power Engineering Department's building.

Along with the photovoltaic power plant description, in this paper is proposed a study case which aims to determine the level of coverage with electricity while the power plant is supplying several consumers with different operating regimes.

3. The Description of the Photovoltaic Power Plant

The photovoltaic power plant has two main components. The external one consists in 18 photovoltaic polycrystalline panels. Some specific parameters of the panels are:

a) panel efficiency: 14.75%;
b) rated power for each panel: 240 W, 60 cells;
c) panel's maximum power voltage: 29.2 V;
d) panel system's voltage: 48 V;

The photovoltaic panels are mounted on the Faculty's High Voltage Laboratory's wall, being south-west oriented. There are six parallel connected rows, each row containing three series connected photovoltaic panels. The panels were installed forming the faculty's traditional acronym "ETH". The photovoltaic panels are lighted in an architectural manner from the top through a LED system, each lamp having a 20 W rated power. The lamps are supplied with the electricity produced by the photovoltaic panels.

The internal part of the photovoltaic power plant consists of: a battery bank of four accumulators, single-phase inverter, charge controller, protection and monitoring systems and two measuring blocks. The inverter along with the charge controller and the protection and monitoring systems are embedded in a single complex system. (Outback Power, 2008)

The electricity provided by the photovoltaic panels is stored in a four accumulators' battery bank. Each accumulator has a 12 V rated voltage, the entire system's rated voltage being of 48 V, as the accumulators are series connected. The rated capacity of each accumulator is 250 Ah.

The measuring blocks are used to record the energy consumed by the connected loads and also the amount of electricity taken from the utility grid to power the loads when solar resource is unavailable.

A general description of photovoltaic system is depicted within the block diagram presented in Fig. 2.

The photovoltaic power plant can operate in several regimes, both Off-grid and On-grid. The Off-grid mode is known as Automatic Generator Start

(A.G.S. Mode), and basically consists in the use of a diesel generator as a backup for supplying the load demands when the sun is unavailable.

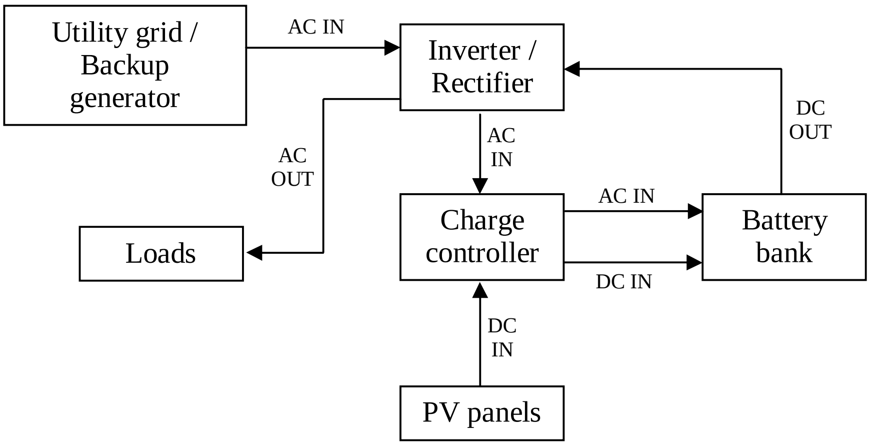

Fig. 2 – Block diagram of the photovoltaic system.

The On-Grid mode can be seen as interactive or non-interactive in respect with the utility grid. In the interactive mode, the energy produced by the photovoltaic panels can be delivered straight into the utility grid. Obviously specific conditions must be met.

In the non-interactive On-grid mode there are two possibilities to operate the photovoltaic power plant. First is known as a High Battery Transfer mode (H.B.X. Mode), in which the loads are mainly powered from the PV panels through battery bank and inverter. The utility grid is used as backup only when the solar resource becomes unavailable and the batteries are discharged.

There is the possibility to recharge the batteries from the AC utility grid, this being useful only if there are several consecutive days without sun. Generally, the batteries will recharge when sun shines again. After the batteries are recharged the system will switch automatically, dropping the utility grid and powering the loads again from the PV panels.

The other way is known as Grid-Use Mode in which the loads are supplied from the grid only on specified time intervals (specific days and hours can be set).

4. Study Case

A study case was conducted in order to assess the photovoltaic power plant's capacity to supply with electricity several consumers with different operating regimes.

In this sense the photovoltaic power plant was set to operate in the

H.B.X. Mode in order to supply the loads as much as possible from the PV panels. For the night time and cloudy days, the load demands were fulfilled from the utility grid, as the batteries discharged.

The utility grid was used only if the battery bank's voltage had dropped below 48 V (critical voltage which stands for a 50% state of charge) for at least six minutes, this time interval being known as critical time. The switch in supply from battery to utility grid is made automatically without any effect on the loads operating regime.

As the sun returned and PV panels recharged the batteries, the system automatically dropped the utility grid, and reconnected the loads to the PV panels. The switch was made only if the battery bank's voltage was over 53 V (which corresponds to a 100% charge level) for at least 30 minutes.

The behaviour of the PV power plant in this operating regime was analyzed in two phases. Thus, in the first phase the PV power plant was used to supply with electricity the lighting system of Power Engineering's building first floor. Basically, there are five offices, three laboratories, one seminary room, two workshop, three storerooms, two main corridors and two secondary corridors. In order to ensure the lighting for all these rooms a number of 71 fluorescent lamps are used, each having a 40 W rated power. Thus, the total installed power of the loads is of 2.84 kW.

The first phase of the study extended between March the 15th and April the 12th 2016. In this period, the total consumption of the loads was of 160 kWh, of which 118 kWh were taken from the utility grid and only 42 kWh were delivered by the PV power plant. Thus, it results that only a quarter of the energy was provided by the PV panels.

This small share can be explained by the operating regime of the lighting system, as usually there is no need to turn on lights on sunny days. Obviously, the lighting system is not the best type of consumer for a PV power plant.

Another cause of this small share of the energy supplied from the panels is that in the analyzed interval there were several days with no sun at all. This can be identified from the daily variation of the energy consumption which is represented in Fig. 3.

The curve dotted with triangles represents the daily amount of energy provided by the PV power plant and, as it can be seen, there are five days with no energy delivered. The diamond and square dotted curves describe the variation of total daily consumption and the energy taken from the utility grid.

In order to obtain a better performance of the PV power plant in the second phase of the study a new type of loads was considered. Thus, along with the lighting system from Phase I, three refrigerators were connected increasing the total installed power to 3.74 kW. Also, is important to mention that the refrigerators have a more proper operating regime than the lighting system.

This second phase extended between April the 13th and May the 10th 2016. The total consumption increased to 211 kWh, of which 125 kWh where taken from the grid and the rest of 86 kWh were provided by the PV power plant. In this phase the PV power plant provided approximately 40% of the total consumed energy, which represent a quite fair result in comparison with the values from the first phase of the study.

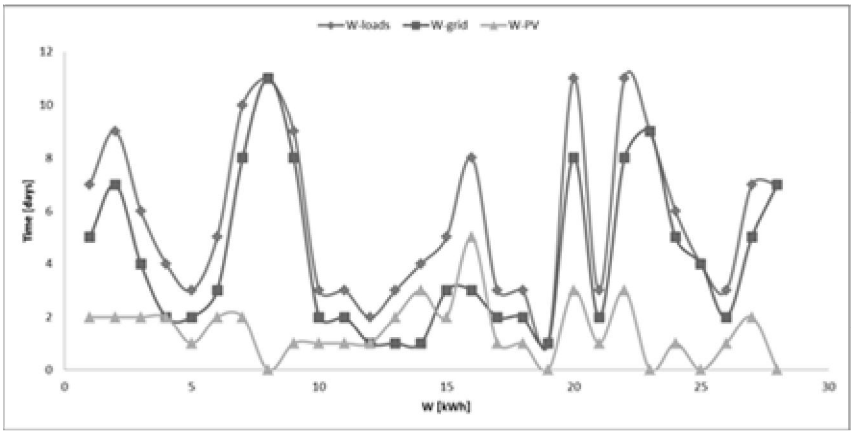

Fig. 3 – The daily consumption on the Phase I of the study.

These results are explicable due to the more constant operating regime of the new connected consumers, and also to the fact that in this period there was only a single cloudy day. This is obvious from the daily energy consumption variation from Fig. 4.

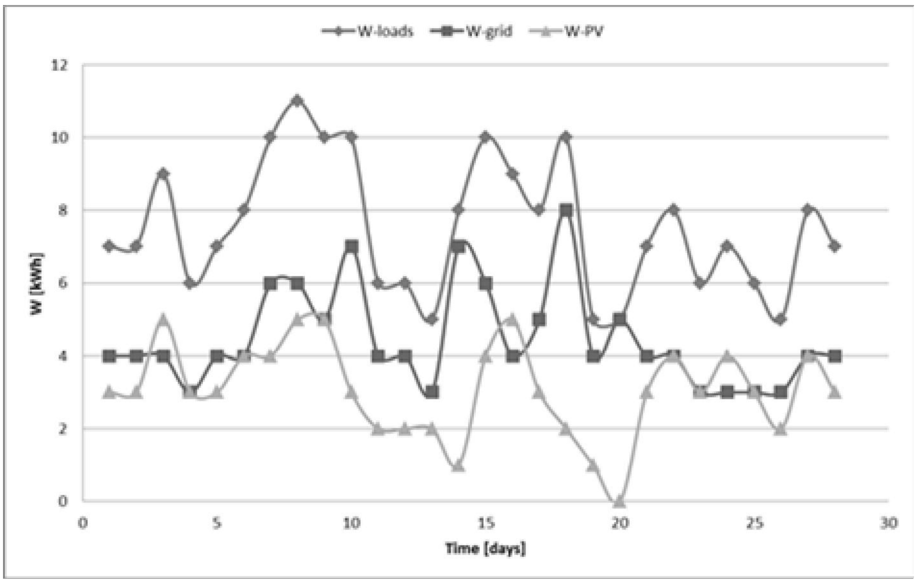

Fig. 4 – The daily consumption on the Phase II of the study.

The code used to differentiate the curves is identical to the one used in Fig. 3. Thus, the triangle dotted curve represents the daily variation of the energy delivered by the PV panels. The much better response of the PV power plant in the second phased is also strongly influenced by the fact that this phase was extended between April and May, which is surely a better time interval in terms of solar potential than the one from the first phase. As these two study cases were conducted in different time periods and with different loads profiles, a normalization of the recorded data is imposed in order to properly compare the results between the obtained values. Consequently, all data were normalized considering the total energy consumption recorded on both phases (371 kWh). The obtained values are presented in Table 1, where W_T is the total energy consumed by the loads, W_G is the energy provided by the utility grid when used as a backup, and W_{PV} is the energy output of the photovoltaic power plant.

Table 1
The Normalized Values of the Recorded Energy Data

Study phase	W_T p.u.	W_G p.u.	W_{PV} p.u.
Phase I	0.4313	0.3181	0.1132
Phase II	0.5687	0.3369	0.2318

As it can be seen, the loads' consumption is almost 13% higher in the second phases of the study, due to a more proper load profile. As the amount energy taken from the utility grid is almost the same in both phases, the energy output of the photovoltaic power plant is more than double in the second phase, due to the better illumination conditions in April and also to the consumption's growth recorded in this phase.

5. Conclusions

As the photovoltaic conversion of the solar energy became a significant source of electricity, a small photovoltaic power plant, with a rated power of 4.32 kW, was installed at the Electrical Engineering Faculty of Iasi, Romania. The main goal is to offer the students the possibility to study on such type of power plant. On the other hand, the electricity produced by the PV power plant is used to supply several consumers from the Power Engineering Department's building.

In this paper the photovoltaic power plant was presented, along with some study cases which aimed to determine the operating regime efficiency of the plant.

In the first phase of the study the PV power plant was used to supply an area of the lighting system of the building. The results were not so great, as only a quarter of the total consumed energy was given by the PV power plant. This fact was determined by the operating regime of the lighting system and also by the fact that in the period in which the measurements were conducted (March to April) the solar potential was not so great.

In the second phase, along with the lighting system new consumers were connected, increasing the total power of the loads. But more important is the fact that the new consumers (three refrigerators) had a more constant operating regime than the lighting tubes. As consequence, the PV power plant was able to support like 40% of the total consumption.

Obviously, a lighting system is not the best type of consumer for a photovoltaic power plant. New type of consumers should be considered, in order to fully benefit of the photovoltaic power plant capability.

Part of research from this article was presented at the 2016 International Conference and Exposition on Electrical and Power Engineering, EPE2016, event organized by the Faculty of Electrical Engineering, "Gheorghe Asachi" Technical University of Iaşi.

REFERENCES

Barla E., Badea G., Porumb C., *Photovoltaic Potential from Solar Database Evaluation*, Journal of Sustainable Energy, **1**, *1*, 28-31 (2010).

Banu I., Istrate M., Machidon D., Pantelimon R., *Aspects of Photovoltaic Power Plant Integration in the Romanian Power System,* Proc. of the IX[th] Internat. Conf. on Industrial Power Engineering, CIEI 2014, May 2014, Bacău, Romania, 13-20.

* * * *Capacitatea totală de producere instalată şi disponibilă în SEN diferenţiată pe surse primare de energie*, CNTEE Transelectrica S.A., http://www.transelectrica.ro/web/tel/productie, 2017.

* * * *Global Energy Statistical Yearbook*, Enerdata, 2016.

* * * *Directive 2009/28/EC*, European Commission, April 23, 2009.

* * * *Energy Efficiency and its Contribution to Energy Security and the 2030 Framework for Climate and Energy Policy,* European Commission, Communication from the commission to the European Parliament and the Council, 2014.

* * * *Renewable Energy Statistics*, Eurostat, May 2015.

* * * *Primary Production of Renewable Energy by Type*, Eurostat, 2016.

* * * *Hotărârea Guvernului României 994/2013 privind aprobarea măsurilor de reducere a numărului de certificate verzi în situaţiile prevăzute la art. 6 alin. (2) lit. a), c) şi f) din Legea nr. 220/2008 pentru stabilirea sistemului de promovare a producerii energiei din surse regenerabile de energie,* Monitorul oficial al Romaniei, nr. *788*, 16 Decembrie 2013.

* * * *Nota privind cota obligatorie de energie electrică produsă din surse regenerabile de energie care beneficiază de sistemul de promovare prin certificate verzi pentru anul 2017,* ANRE, 2016.

* * * *Legea energiei electrice*, Parlamentul Romaniei, Legea nr.*13*/2007, Monitorul oficial al Romaniei, Partea I, nr. *51*, 23 January 2007.

* * * *Legea nr. 220/2008 pentru stabilirea sistemului de promovare a producerii energiei din surse regenerabile de energie*, Parlamentul Romaniei, Monitorul oficial al Romaniei, Partea I, nr. *743*, 3 November 2008.

* * * *MATE System Controller and Display Installation and User Manual for the OutBack MATE and MATE 2*, OutBack Power, 2008.
* * * *Global Horizontal Irradiation map of Romania*, Solargis, http://solargis.com/products/maps-and-gis-data/free/download/romania, 2017.

CONSIDERAȚII ASUPRA CONVERSIEI FOTOVOLTAICE A ENERGIEI SOLARE ÎN ROMÂNIA

(Rezumat)

În prezent energia solară este una dintre cele exploatate resurse regenerabile de energie. Aplicațiile conversiei termice, respectiv fotovoltaice a energiei solare sunt răspândite atât la scară mică, pentru acoperirea directă consumului casnic, cât şi la scară mare, în centrale electrice de mare putere. Lucrarea de față doreşte să prezinte, succint, câteva aspecte referitoare la conversia fotovoltaică a energiei solare în România. Spre exemplificare se prezintă centrala fotovoltaică de 4.32 kW putere instalată din dotarea Departamentului de Energetică a Facultății de Inginerie Electrică, Energetică şi Informatică Aplicată din Iaşi. Aceasta este folosită atât în scopuri didactice, cât şi pentru asigurarea necesarului de energie electrică a unor consumatori. Sunt prezentate, de asemenea şi o serie de date rezultate obținute în urma unor studii efectuate asupra funcționării centralei fotovoltaice.