UNIVERSITY OF CRAIOVA
FACULTY OF ELECTRICAL ENGINEERING
Doctoral School of Electrical and Energy Engineering
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Ing. Gina-Mihaela LUNĂ

-Summary of the Doctoral Thesis-

"RESEARCH ON THE SUPPLY OF ELECTRICITY TO CONSUMER THROUGH THE USE OF RENEWABLE ENERGIES"

Scientific supervisor:

Prof.univ.dr.ing. Sergiu IVANOV 01.10.2018 - 03.09.2021

Prof.univ.dr.ing. Gheorghe MANOLEA 08.09.2021

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Justification of the theme

In 2018 - 2020 I worked for a company that produces and supplies electricity, offering advice for the installation of photovoltaic panels, people who enroll in the financing program "Green House Photovoltaic", but also people who want to purchase photovoltaic panels from your own investment.

Since September 2020, I work for a partner company of an electricity supplier and producer, the department of „Activation and management of customers", where I meet, daily, information on the amount of electricity generated by photovoltaic systems, but also questions about how to become a prosumer.

From this experience we concluded that the electricity market is of interest to the population and that there are many people who want to produce electricity from renewable sources, but do not have the necessary information about photovoltaic systems, their sizing, projects funded by the Environment Fund Administration and on the amortization of investments in this field.

The importance the actuality of the theme

Renewable energy sources are increasingly used to produce electricity [13], [20], [21], [24], [29], [31] - [33], [79] being alternative solutions to reduce the use of fossil fuels, thus helping to reduce greenhouse gas emissions, diversify energy supply, reduce dependence on volatile but also uncertain markets for fossil fuels, especially gas and oil, can also stimulate employment. work, with the emergence of new jobs in the sector of new "green" technologies [11].

In 2018, the European Union (EU) has set that by 2030, 32% of EU energy consumption will come from renewable energy sources [106].

According to a report published by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations (UN), in order to limit the effects of global warming, the use of fossil fuels must be gradually reduced so that by 2100 they will be complete eliminated [98].

In Romania, photovoltaic energy is increasingly used, as evidenced by the "Green House Photovoltaic" program between 2019 and 2021. Through this program, you can get a maximum of 20.000 lei for the implementation of a photovoltaic system, being funded by the Ministry of Environment, Waters and Forests through the Environment Fund Administration [157], [158], [160].

Framing the theme in international concerns.

Global warming generated by greenhouse gases is an international concern, as evidenced by the EU's involvement in this sector, by setting targets.

In 2014, the policy framework on energy and climate for 2030 was established, which includes a set of targets for the years 2021 - 2030. In line with these targets, the EU has committed itself to reducing greenhouse gas emissions by 2030. greenhouse gases by at least 40% compared to 1990.

The framework includes policies aimed at increasing the competitiveness of the security and sustainability of the EU energy system and economy and has supported the need for national energy and climate plans, as well as long-term strategies [131], [132].

At the international level, renewable energies are a concern both for individuals such as writers [1], [38], [41], [43], [46], [47] or doctoral students [10], and for organizations including International Renewable Energy Agency (IRENA) [87].

Framing the theme in national concerns.

Climate change and the widespread use of renewable energies are a concern of Romania, as evidenced by the legislative changes, presented in the „National Strategy for Sustainable Development of Romania 2030" [170], in the subchapter "Renewable energy and energy efficiency", which presents „National Action Plan in the field of energy efficiency", approved in 2015, and is currently working on the „National Energy Plan - Climate Change" [152], which is developed on the basis of the „Draft Regulation on energy governance" , which includes the necessary measures and objectives, which are applied in this field at EU level [167].

Romania's objectives until 2030, regarding the renewable energy sector, are:

- an increase of 30.7% in the share of renewable energy sources and low carbon fuels in the transport sector, including alternative fuels;
- achieving a transparent and stable regulatory framework in the field of energy efficiency in order to attract investment [170].

Concerns regarding the uses of renewable energies have several organizations in Romania such as the University of Craiova [2] - [7].

The problem proposed for solution

The topic of the doctoral research was approached considering:

- lack of information about photovoltaic systems accessible to individuals;
- lack of information regarding their sizing;
- lack of a methodology for calculating the payback period;
- lack of a clear methodology for individuals on accessing non-reimbursable funds.

The purpose of the thesis

The aim is to expand the knowledge and use of renewable resources, namely photovoltaic energy for consumers in rural and urban areas.

The objectives of the doctoral thesis

The objectives of this research process are the following:

O1. Carrying out an opinion poll, in order to highlight the degree of information of the participants, on the photovoltaic systems and a practical guide for their installation;

O2. Development of an interactive program for calculating the electricity demand of a home, depending on electricity consumption or consumers used, in order to determine the required number of photovoltaic panels;

O3. Carrying out case studies, in order to highlight the impact of weather conditions and the location of photovoltaic panoramas on the amount of electricity generated by photovoltaic systems, but also the importance of detailed information to the population on the use of renewable energy.

Doctoral research methodology

For the elaboration of the doctoral thesis I documented:

- books: [1], [8], [11] - [15], [20] - [39], [41], [43], [45] - [47], [49], [50], [59], [61] - [63], [65] - [78], [80], [83];
- articles: [2] - [7], [81];
- doctoral theses: [10], [16], [17], [40], [64], [79], [82];
- patents: [9], [18], [19], [42], [44], [48];
- normative and standard acts: [97], [101], [109], [125], [125], [130], [134] - [148], [152], [155], [156], [165] - [167];

- web pages of some companies, organizations and bodies with activity in the field: [84] - [96], [98] - [100], [102] - [108], [110] - [123], [126] - [129], [131] - [133], [149] - [151], [153], [154], [157] - [164], [169] - [176].

Of real use to me was the method of observation, applied during the case study in which the components of the studied systems were established and the orientation of the photovoltaic panels on the roof.

The statistical method was used to carry out the opinion poll in order to highlight the degree of information of individuals regarding renewable energies and thus photovoltaic energy.

The experimental method was used to determine the influence of weather conditions on the amount of electricity generated by photovoltaic systems.

The research activity carried out within the doctoral thesis had direct implications in the development of a software tool for sizing the on grid or off grid photovoltaic system.

Doctoral thesis structure

The thesis is structured in six chapters

Chapter 1 - Introduction

Chapter 2 - Analysis of the possibilities of capitalizing on photovoltaic energy

It includes the Romanian legislative framework on electricity supply to consumers, by using renewable energies, methods and tools used to assess solar energy potential, photovoltaic energy applications and presentation of on grid or off grid photovoltaic system components, as well as their role.

Within this chapter is a study conducted over a period of 62 days in order to obtain information on the value of average power produced and consumed at certain hours, on the contribution of conventional and renewable energy sources in generating average power but also on energy obtained from the photovoltaic source at certain hours.

Chapter 3 - Research on the availability of consumers to implement photovoltaic systems

It contains an opinion poll, in order to highlight the degree of information of the participants.

Also in this chapter, a guide for the implementation of the photovoltaic system was developed in order to provide the necessary information to people who want to know and invest in a photovoltaic system. It includes the logical scheme of the advantages and disadvantages of photovoltaic systems, the logical scheme of the documents necessary to connect the photovoltaic system to the national network and the stages of implementation of the photovoltaic system through the non-repayable financing program „Green House Photovoltaics".

The last part of this chapter presents the steps to be followed for the implementation of the photovoltaic system and the measuring devices used for its operation.

Chapter 4 - Contributions regarding the sizing of photovoltaic systems

Contains an application to calculate the electricity needs of a home.

Through this application, the return on investment can be determined.

In the second part of the chapter, the sizing of several case studies was carried out, with the help of consumers used in the home but also with the help of the electricity bill.

The sizing of the photovoltaic system is the most important stage, before its implementation.

Sizing can be done starting from the information in the electricity bill for those who are already connected to the network or knowing the type of consumers that will be used in the home, but for this it is necessary to know the nominal power of each consumer and their time of use, for beneficiaries who are not connected to the network.

Chapter 5 - Contributions regarding the study of the on grid photovoltaic systems

It includes six case studies conducted on grid photovoltaic systems implemented in Dolj County, to identify the influence of average temperature, duration of sunshine, direct solar radiation and average wind speed on the amount of electricity presented.

The values of electricity production were monitored using the application „Fusion Solar". For each case study it is indicated:

- installed power;
- the area in which it is mounted: rural or urban;
- orientation of the panels;
- values of meteorological parameters;
- variation of average production and average temperature;
- variation of average production and duration of sunshine;
- energy production on days when the sun was covered by clouds;
- variation of average production and direct solar radiation;
- average production and average wind speed;

Dissemination of results

The results obtained during the elaboration of the thesis were disseminated by publishing an article at the international conference „Modern Power System 2021" [54] and in the national journal „Romanian Journal of Civil Engineering" [56].

Conclusions

Conclusions on the average power produced by the photovoltaic source, in certain time intervals

A study was carried out over a period of 62 days, at 08:00, 10:00, 12:00, 16:00, 18:00 and 20:00, in order to highlight the maximum and minimum values of the average power produced from renewable and conventional sources, as well as the time at which the average power registers maximum values.

The photovoltaic source is one of the renewable sources subject to the study, and after analyzing the values obtained, it was concluded that at 12:00, the average power from the photovoltaic source has maximum value and represents 8.3% of the average total power injected into the system.

The lowest value was recorded at 20:00 and represents 0.47% of the total average power injected into the system.

Although the conclusion seems obvious, it provides documented information.

Conclusions on the availability of the implementation of photovoltaic systems

An opinion poll was conducted to answer questions such as: the importance of electricity for respondents, how many of the participants have heard about renewable energy sources, how much information do respondents have about photovoltaic panels, how many are willing to invest in a photovoltaic system, what are the reasons why the respondents do not want to invest in such a system, if they know the non-repayable financing program „Green House Photovoltaics", how many want to obtain these grants if they have the necessary information and the profile of the participants

It is mentioned that over 50% of the respondents were men. Also, the respondents are between 26 and 33 years old, they are full time employees and their residence is in an urban area, living at home.

From the response of the participants, the following were concluded:

- electricity is important for participants;
- 88.23% of the respondents heard about renewable sources and the main source of information being the Internet;
- only 2.2% of people are extremely informed about the photovoltaic system and implicitly what this type of renewable energy entails;
- 38.23%, have average information on this subject;
- 55.88% of people want to invest in such a system;
- the main reason why the other participants do not want this is the lack of information, 22.79% of people giving this answer.

Conclusions regarding the sizing of photovoltaic systems

To achieve the O2 objective "*Development of an interactive program for calculating the electricity demand of a home, depending on electricity consumption or consumers used, in order to determine the required number of photovoltaic panels*" a software application [94] based on on two sizing methods (consumer method and electricity bill method).

The method of sizing the photovoltaic system based on consumers requires accurate knowledge of the nominal power of consumers but also the time of use, which is usually estimated. Deviations can lead to incorrect sizing of the system, respectively to the generation of an insufficient amount of electricity, if the number of panels is less than necessary.

The method of sizing the photovoltaic system based on information from the electricity bill, although it leads to correct results, can be applied only in the case of homes that are already connected to the national electricity distribution network.

With the help of the designed software application is calculated, based on the mentioned methods, the daily electricity consumption, the installed power of the system that will or will not be implemented and the required number of photovoltaic panels depending on the power provided by a panel, selected from a list. predefined.

Also with the help of this software application you can determine the payback period, depending on the amount of electricity used by consumers to be used.

Specific government programs, in particular the „Green House Photovoltaics" program, encourage individuals to implement photovoltaic systems, as evidenced by the fact that in the six case studies, photovoltaic systems were implemented through this program.

The fact that three of the owners who implemented the photovoltaic system through the „Green House Photovoltaics" program did not size the system according to the need for electricity, but according to the amount granted by Environment Fund Administration, shows that the problem from which it initially started, respectively the lack of information regarding their sizing was correctly identified and formulated.

The big difference between the price at which the supplier buys the electricity injected into the network by a prosumer (eg 0.196 lei / kWh) and the selling price (eg 0.74 lei / kWh), as well as the procedure to be followed to obtain the necessary approvals for connection, causes some of the owners of photovoltaic systems to use photovoltaic energy only for their own consumption (eg 4.4.1. Representative case).

Conclusions on the impact of meteorological conditions on the production of electricity generated by the implemented photovoltaic systems

The analysis showed that:

- the month in which the highest amount of electricity was generated was July, the month in which the highest average temperature was recorded, the duration of the sun's brightness was the longest and the direct solar radiation was maximum;

- the average wind speed had the highest values in January, when the electricity generated by the photovoltaic system had a minimum value, but also in May, when the photovoltaic system generated a large amount of electricity;
- we can say that the average temperature, the duration of sunlight and direct solar radiation influence the amount of electricity generated by the photovoltaic system but not the average wind speed which has approximately constant values during the seven months of study.

Carrying out a comparative analysis between on grid photovoltaic systems with an installed power of 3 kW, it was concluded that:

- the system that recorded the lowest production in one day, was the one in the rural area, in Celaru town, with the panels mounted on the eastern side, the registered value being 0.06 kWh. The lowest electricity production generated by the photovoltaic system implemented in Malu Mare town was 0.68 kWh, but this minimum production was the highest compared to the other two photovoltaic systems with an installed power of 3 kW;
- the highest value, of the maximum production, was generated by the system implemented in Malu Mare town, the value being 24.89 kWh, and the lowest value, of the maximum production, was registered by the photovoltaic system implemented in the urban area, Craiova locality;
- in January, the production registered the lowest value, the system implemented in Celaru town, generated the smallest amount of electricity, followed by the system implemented in Popoveni neighborhood, the third place being occupied by the photovoltaic system from Malu Mare town;
- within a month, the largest amount of electricity was generated by the photovoltaic system implemented in Malu Mare town, the second place being occupied by the system from Popoveni neighbourhood, the last place being occupied by the system implemented in Celaru town;
- depending on the electricity production, the photovoltaic system implemented in Malu Mare town, is the most efficient, because it generated the largest amount of electricity, both at the level of a day and at the level of a month;
- analyzing the results obtained, the least efficient system is the one implemented in Celaru town, due to improper orientation of the solar panels.

Contributions

Theoretical contributions:

- Development of logic schemes for analyzing the advantages and disadvantages of photovoltaic systems, in order to help individuals make the decision to implement these energy sources.
- Realization of a logical scheme for the identification and presentation of the documents necessary for the implementation of a photovoltaic system.
- Realization of a logical scheme for the identification of the documents necessary for the connection of the photovoltaic system to the national network.
- Creating a logical scheme to help individuals more easily identify the steps to be taken to implement a photovoltaic system.
- Identifying and presenting the necessary steps for the applicant in order to enroll in the non-repayable financing program „Green House Photovoltaics".
- Use of the „Fusion Solar" application to monitor the electricity production generated by the six on grid photovoltaic systems.

Experimental contributions:

- Conduct an opinion poll to answer questions such as the importance of electricity for respondents, how many are willing to invest in a photovoltaic system and how many want to obtain grants if they have the necessary information.
- Carrying out a study for a period of 62 days, at 08:00, 10:00, 12:00, 16:00, 18:00 and 20:00, in order to highlight the maximum and minimum values of the average power produced from renewable and conventional sources, as well as the time at which the average power registers maximum values.
- Carrying out a study, for a period of 62 days, 13.05.2021 - 13.07.2021 in order to highlight the values of the average power from each type of renewable or conventional source, at 08:00, 10:00, 12:00, 16:00, 18:00 and 20:00, in order to obtain the main source for generating the average power at national level and to ascertain the time at which the photovoltaic source has the lowest but also the highest values.
- Carrying out a study over a period of 189, 192 and 212 days, to observe the influence of average temperature, duration of sunshine, direct solar radiation and average wind speed, on the electricity generated by the photovoltaic systems subjected study.
- Carrying out a comparative analysis for the photovoltaic systems that were studied, with the installed power of 3 kW, in order to highlight the efficiency of the system according to the analyzed meteorological parameters and according to the orientation of the photovoltaic panels.

Software contributions:

- Development of a software application for sizing the photovoltaic system, in the case of the on grid system, using the information from the electricity bill.
- Development of a software application for sizing the off grid system using the consumers used.
- Development of a software application that allows a potential user to determine the amount to be invested.
- Development of an application for calculating the payback period, expressed in months.
- Development of a software application that allows a potential user to determine the amount to be invested.

The degree of achievement of the proposed objectives

The first objective of the thesis „Conducting an opinion poll, to highlight the degree of information of the participants, on photovoltaic systems and a practical guide to their installation" was achieved by questioning 136 people in Dolj County and a guide containing four steps required to install the photovoltaic system.

The second objective of the thesis „Development of an interactive tool for calculating the number of panels needed, depending on the consumers used or expected or according to the history of electricity consumption" was achieved by creating an application described in Chapter 4.

The third objective of the thesis, „Carrying out case studies, in order to highlight the impact of weather conditions and the location of photovoltaic panoramas on the amount of electricity generated by photovoltaic systems, but also the importance of detailed information population on the use of renewable energies" was achieved by conducting the analysis of electricity production generated in six locations over certain periods of time, as shown in Chapter 5.

Future research directions

The opinion poll presented in Chapter 3 can be developed by questioning a larger number of people, from several counties, to identify several reasons why the implementation of photovoltaic systems is not desired.

The program for sizing photovoltaic systems, presented in Chapter 4, can be developed by entering data such as average temperature, duration of sunshine, direct solar radiation and average wind speed, in Romania and other countries of the Earth, for sizing them as closer to the efficiency they have, depending on the weather conditions, but also by creating a catalog from which to select the components or the photovoltaic system, automatically determining the amount invested.

As the photovoltaic systems presented in Chapter 5 were monitored over a period of seven months, the study can be extended over a longer period, to see how they influence weather conditions, the production of electricity generated by them.

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