Problems of driving and modeling of the electroenergetic systems

PhD thesis – Abstract

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The PhD thesis with the name "Problems of driving and modeling of the electroenergetic systems" presents a synthesis of the results of the author's research, interpreted during the activity carried out within the Department of Automatic and Applied Informatics of the Faculty of Automation and Computers at the Politehnica University from Timisoara , in order to obtain the title of doctor in the field of "Systems Engineering". The thesis is structured in 7 chapters, with 143 pages, and a list of 156 bibliographic titles, of which 11 belong to the author.

The first chapter presents the main objectives of the paper based on the concerns about renewable solar resources.
The opportunity arises from the current large-scale concerns about renewable solar resources for the purpose of obtaining electricity called "green". The development of solar power systems was made possible on the one hand as a result of technological research inovations in the field of electronics, power electronics, materials, new discoveries in physics, the evolution of systems and management strategies, and on the other hand, European policies, national and regional areas for attracting renewable energy in obtaining electricity.
In today's global energy systems, the production of electricity from renewable resources presents a big interest, especially since on the one hand the global reserves of classic fuels: oil, coal, gas, are on the verge of depletion due to the increasing consumption (it doubles from 10 to 10 years) and on the other hand, environmental protection concerns have become a global priority.

In Romania, keeping in mind the solar potential, the opportunity of the paper is fully justified economically, technically and especially ecologically.
The base objective of the paper is to design , drive and analyze the functionality of a solar system so that the solar energy captured is kept at maximum. In this sense, it is considered a solar radiant power that varies in time depending on the weather conditions. So, the value of the electrical power received from the photovoltaic panel must be closely correlated with the value of the solar radiant power, in order to be able to operate at the maximum power points.

- In this sense, the main objectives proposed in the paper are:
  - Development, identification and validation of some mathematical models for photovoltaic panels used in the management of the photovoltaic system.
  - Development of driving structures in order to obtain maximum electricity (maximum power point tracking) under time-varying weather conditions.

Chapter two is dedicated to the critical analysis of the existing solar energy systems, presented in the technical literature, outlining the current state of research on the conversion of solar energy as well as the perspectives for the usage both nationally and internationally. The chapter details the main types of renewable and non-renewable energy sources used worldwide, specifying the advantages and disadvantages of each type of energy. For solar energy, it is concluded that this is most suitable for most isolated communities that are currently supplied with electricity produced by diesel generators, which are not advantageous due to the consumption, limited access to fuel and the increased pollution level. Electricity consumption is much higher in the evening and in the night, when the source of solar energy disappears, or during the day due to power fluctuations caused by weather factors, and this conclude that it is necessary to implement a system to store the energy and to use it to compensate this fluctuations from the day time and to provide to the customers the energy needed at the values and times required by them, and so, photovoltaic panels can provide a complete and functional solution to isolated communities.

Storage systems must take over the power fluctuations that occur due to the variations in the level of solar radiation. Thus, a constant power is transferred into the national power system over a certain period of time, which is particularly important in terms of the dynamic stability of the national power system. The surplus of power from the photovoltaic panels is used to charge the electric accumulators until a 100% charge state is reached, a state estimated by the voltage value at the terminals of the electric accumulator or battery. The transfer of power from the electric battery to the mains is done by usage of a DC-AC converter. Its input voltage is around the nominal voltage of (12, 24, ... [V], (multiples of 12 [V])). The takeover of the surplus power from the photovoltaic panel to the super capacitors is realized by successive charging at the voltage needed at the input of the DC-AC converter. The transfer of power from the super capacitors to the network is also done through a DC-AC converter, specifying that in the case of super capacitors the transfer takes place in a much shorter time. In this mode the electric battery and the super capacitor can operate separately. Super capacitors are used at relatively low power ranges. At MW power, the use of super capacitors is not justified and therefore the storage system contains only electric batteries.

Electroenergetical power systems offer a high-perspective solution in ensuring the electricity needs for every consumer.

Of course, the implementation of these systems based on renewable energy must be based on in-depth and long-term studies on the solar radiation.

The electro energetic systems with photovoltaic panels, also called photovoltaic systems, provide a power that changes slowly over time, directly depending on the radiant solar power that changes as the weather conditions change (clouds, dust, nebulosity). The annual energy received from the sun is much higher than the global energy consumed by the population and this aspect has made this energy source particularly attractive.

Also, this chapter presents in detail the current state of energy conversion systems, presenting the advantages and disadvantages of using this type of energy and the effect of converting energy from solar energy into electrical energy through the photovoltaic effect.

Chapter three is dedicated to the problem of mathematical modeling of photovoltaic panels which are the main components of solar energy systems. Driving of the solar energy systems, so that the operation is in the optimal area - maximum energy captured - requires the use of suitable mathematical models, models that allow at every moment of time to identify the maximum power point easily. So, an original mathematical model for the photovoltaic panel is developed ,based on the function "COS", built through countless experimental tests that finally ended with a model that perfectly fits over the curve of the external characteristic of any photovoltaic panel by simply adjusting some parameters.
The development of this mathematical model done by analyzing the external experimental characteristics and starting from the idea that the shape of the characteristic approximates to the form of the COS function which is on the interval [0 - ∏ / 2], and taking into account that the values of short-circuit currents increase with solar radiant power and the values of the voltages from the open load operation do not depend on the value of the radiant power and they decrease with the increase of the temperature of the photovoltaic panel, and the temperature of the photovoltaic panel influences the value of the short-circuit current, in the sense that it increases directly proportional to the temperature have concluded with a complete and accurate mathematical model.
This model allows the optimal driving of the solar energy systems by determination of the coordinates of the maximum power points. There are also proposed two simplified mathematical models that are considering a constant temperature for situations where a more complex model is not needed and which can be implemented in a physical system very easily without worries related to the computing power of the controller. These models were designed in such a way that are following as closely as possible the external characteristic of the photovoltaic panel by identifying some key parameters. The determination of the coordinates of the maximum power points was performed in the situation where the level of solar radiant power (insulation) is constant, as well as in the case were the level of solar radiant power in conformity with the weather reality that is always variable. This was realized by considering a sinusoidal variation of the level of insolation, a variation that simulates very well the changes due to the factors of the weather reality.

In chapter four is presented in detail the functional analysis of the system with photovoltaic panels considering some specific configurations that are available in most physical systems on the market, tracking the conversion efficiency of each configuration separately. The configuration in which the photovoltaic panel is connected directly with a constant resistance load is relevant because this is present in most individual micro systems with a predominant use in the lighting systems .The configuration in which the photovoltaic panel is connected directly to an electric accumulator is relevant because it is used on large scale in emergency lighting systems. This configuration is treated separately on the case where the load is not adapted and in the configuration where the load is adapted to the external characteristic of the photovoltaic panel.
Another configuration with a big interest value , being the only solution for adapting the voltage provided by the photovoltaic panel system (park) to the battery banc or grid voltage, used in all high power systems, is that the photovoltaic panel is

connected on the inputs of an electric converter (DC- DC) and the output of this converted is connected to the electric batteries that require a different level of voltage and current compared to those provided by the photovoltaic panel park.

A comparative analysis of the system in which the panel is connected to the inputs of a converter (DC-DC) and on the outputs are connected a load, using for the driving algorithm of the classical method from the literature, namely the method perturb and observe, respectively the method developed in the thesis, called the method of canceling the power derivative that uses a small photovoltaic panel to find the coordinates of the maximum power point, and then uses these values to control the entire photovoltaic panel park, by optimally adjusting the converter parameters (DC-DC). The results of the analysis show that the classical method perturb and observe modifies the equivalent load resistance from the photovoltaic panel terminals and aims that the operation of the solar power system is as close as possible to the maximum power point, but this point being unknown, a continuous search operation is performed and the system works always below the maximum power point coordinates. For operation exactly at the maximum power points coordinates, characterized by the values of the optimum voltage and the optimal current, it is necessary to use a driving algorithm that knows these maximum power points and can ensure optimal settings for the (DC-DC) converter , namely the algorithm that it has in its composition the method of canceling the derivative of power. The behavior of the photovoltaic system is also analyzed when changing the load resistance according to the power difference for different values of the parameters of the driving algorithm. An optimal driving algorithm is designed to drive the system into the maximum energy zone , and for reaching this is used the method of canceling the power derivative.

The variations of the significant parameters of the photovoltaic system were determined and analyzed by adapting the load resistance to the value of the received power on the load so that it approaches the maximum power points of the photovoltaic panel. Driving systems that are based on the method of canceling the power derivative were considered and analyzed, considering as reference parameters the optimal current and the optimal voltage, respectively just the optimal current.

Chapter five is dedicated to the presentation of the physical measurement stand, that was intended for the mathematical identification of the proposed mathematical models, the analysis of the optimal functioning of the photovoltaic panel, respectively the validation of the results. The stand has in its composition five photovoltaic panels that are connected to a DC-DC converter module which has for the load an intelligent variable resistor and a small photovoltaic panel connected to a controller, with the role of tracing the external characteristics of the photovoltaic panel for the weather situation from that moment of time in order to optimally drive the panels in that are in the power circuit. It was designed and built a controller based on a microcontroller that allows real-time processing of the data acquired from the photovoltaic panel and from the temperature sensor, in order to control the DC-DC converter in order to provide at the output a maximum power (operating at maximum power points). The smart rheostat made is at the base a power rheostat used as a load. This is moved by a stepper motor which is controlled by another microcontroller system that is equipped with a display and a keyboard that permits the load resistance to be modified by choosing some forms of variation of the resistance in case of considering a given characteristic by simply adjusting some software parameters.

This rheostat was particularly useful during the research period because it was able to simulate different charging states of an electric battery, simulating different power loads in order to analyze the system response. The stand was also equipped with different capacitive, inductive and resistive loads with fixed values, and their connection in the circuit was made through relay circuits that are controlled by a PC using its serial port in order to analyze as much as possible scenarios in a short time interval (to have the same power received from the photovoltaic panel and by doing this to somehow cancel the weather factor.

Chapter six presents some of the measurements made on the stand, that are considered representative. Comparative analyzes were performed for two distinct scenarios: comparative analysis of the results considering different observation steps, as well as of the results obtained using fixed and distinct values for the load resistance for the case were a classical driving algorithm (Perturb and Observe) was used and for the case were the proposed algorithm (canceling the power derivative) by using a schematic that consists just in a photovoltaic panel that directly gives power to a load resistance and by considering four fixed resistance values for the load , tat are near the maximum power point in order to determine the position of the operating point in comparison with this maximum power point, thus demonstrating that at the right choice of load resistance value can be obtained approximately the same performance, not requiring the power electronics that are involved in a DC-DC converter. The analysis reveal that by using the method of canceling the power derivative and by knowing the coordinates of the maximum power point (optimal current and optimal voltage) the maximum power could be captured at a given insolation level. From an energy point of view, an energy surplus was realized, in the proposed version, of about 10% of the electrical energy obtained from the photovoltaic conversion relative to the energy obtained by using the method of Perturb and Observe, by means of which the coordinates of the maximum power points cannot be known. Also were determined experimentally the external characteristics of the photovoltaic panel and an experimental identification of the mathematical model of the photovoltaic panel was performed, considering a constant temperature.

In the final chapter of the paper (Chapter 7), the final conclusions, personal contributions and possible future research directions that can be focused on the development of new models for other types of panels, new strategies for driving the system to the maximum functioning points. Regarding the actual stand it can be improved by implementing additional functions such as the information of the user of presence of any faults or maintenance periods required on the panel park.
Also, the operating parameters of the controller can be recorded for statistical purposes or a communication interface with other controllers existing on the market can be implemented.

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