Implementing Optimization Methods into Practice to Enhance the Performance of Solar Power Systems

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***Abstract*—The use of contemporary technological tools, as well as the modernization of curricula in the field of electronic and electrical engineering, is one of the main objectives of the academic staff at the Universities. Efforts to improve curricula and scientific research infrastructure find strong support from the CBHE programs funded by the EU. The purpose of this work is to include the optimization methods for improving of the photovoltaic system's performance using the digital technologies which develop students' theoretical and practical skills for a sustainable development in the field of energy. Optimizing of the photovoltaic system through the addition of a booster, MPPT controller to the existing architecture, as well as with the help of SIMULINK will increase the energy efficiency of the photovoltaic system, increasing the University's economic benefit and moreover, the ecological benefits for the population. The implementation of the optimization algorithms will increase the simulation skills of the academic staff and students for a more in-depth analysis related to the implementation of RES, an analysis which until now has only been developed through software data collection methods of the system. As case study it is the utilization of photovoltaic system in the University of Durres area, which is a sustainable development area in both the public and private sectors after the 2019 earthquake. The study brings a transdisciplinary approach that contribute in the education of the new generation towards a green society and economy. It includes knowledge of the field of electrical engineering in the direction of increasing the performance of renewable energy systems as well as the analysis of electronic circuits with the help of optimization algorithms and different ICT tools.**

Keywords*—Optimization; photovoltaic systems; education; performance; controller; SIMULINK

I. INTRODUCTION

The application of optimization techniques to enhance the efficiency of a photovoltaic (PV) system combines technology, design, and maintenance procedures. To make sure that the PV system runs at its maximum power point and maximizes energy output under variable weather conditions, we must use inverters or MPPT charge controllers.

The developed analyzes serve to create the history of the photovoltaic system' using, the analytical development of the current situation and to increase the skills in the design of further projects by implementing Renewable Energy Sources in general and photovoltaic systems in particular. These methods can also be used by curriculum programs of Albanian Universities and the Western Balkan' Universities in terms of highlighting the advantages of environmentally and economically sustainable development.

The PV system's performance can be immediately monitored by setting up a monitoring system. Data analysis allows us to find trends, solve problems, and gradually improve system performance.

The optimization strategies have been applied in this paper for improving the performance of solar energy systems in generally for all photovoltaic systems. The University of Durres is used as the case study due to this, since a photovoltaic system was installed there thanks to the several funds invested by Erasmus+ programs.

Aleksander Moisiu University of Durres (UAMD) is Leader or Partner Institution for more than a hundred of International projects. We can mention the project “Development and implementation of multimedia and digital television curricula (DIMTV)”, “Accelerating Western Balkans University Modernization by Introducing Virtual Technologies” (VTech@WBUni) projects [1], which AMUD has been Leader Institution. Participation in projects has significantly served in increasing the capacities of the academic staff of Aleksander Moisiu University of Durres, in exchanging of experiences for the academic, administrative staff as well as students among partner universities in the region and European, improved the research infrastructure, participate in various activities such as workshops, conferences, seminars, etc.

Aleksander Moisiu University of Durres was a partner institution in the “Knowledge Triangle for a Low Carbon Economy” (KALCEA) project, whose objectives enabled the development and growth of cooperation between university, business and scientific research centers. One of his objectives was to emphasize the urgent need for universities to increase their role in the social and economic development at the local and regional level [2]. Based on the establishing of strong connections with business/industry sector, improving technical and human capacities, improving research activities in cooperation with industry sector, improving the skills of students based on the market needs and more.

Through the knowledge triangle mechanism (knowledge-research-innovation) has been improved the curricula with innovative knowledge in the field of renewable. We have studied the photovoltaic system installed on the roof of one of the buildings of the university campus in Spitalle, Durrës, which was financed by EU funds.

For the design and installation of the photovoltaic system at the University of Durres, a service company in the field of renewable resources in Albania was contacted. The block scheme of his realization is shown in Fig. 1.

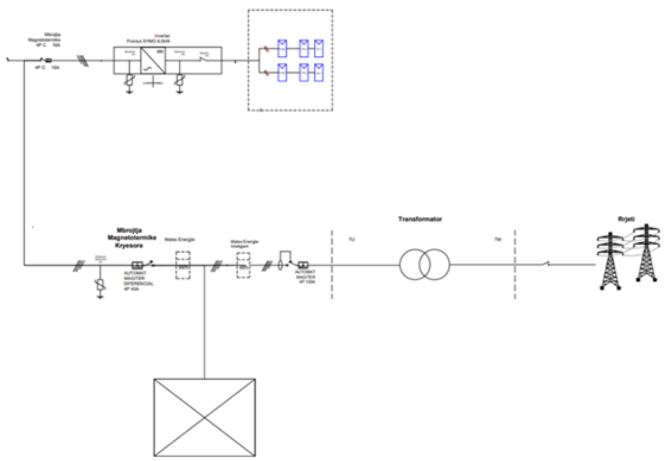


Fig. 1. The scheme of the implementation of the photovoltaic system at the university campus of Durres

The purpose of this paper is to improve the architecture of the photovoltaic system with added elements in the installed system with the purpose of improving the performance of the power generation system with the help of Simulink [3]. Improving the photovoltaic systems architecture will be done by adding a booster, MPPT controller, as well as using optimization algorithms in this controller [4]. In this study, the P&O algorithm will be used to compare the photovoltaic system's performance.

Additionally, the solar system will be examined for varying temperatures and irradiations utilizing a booster and two different types of controls (PD and PI type controllers). We must weigh the advantages and disadvantages of each technique used to determine which strategy will enhance solar system performance in general for all users and in particular for UAMD.

II. Literature Review

Researchers, academic institutions, and Universities have attempted to increase the efficiency of photovoltaic systems. Let's review a number of these researchers and their suggestions for enhancing photovoltaic system performance.

The theories of PV systems and MPPT approaches are introduced by A. Sadick, who also provides the mathematical modeling processes for the DC-DC boost converter and the PV system. Simulations and tests were conducted under various environmental conditions using two types of solar systems: one with the P&O algorithm and the other without [5].

The performance of a multiple gain boost converter connected to a solar photovoltaic (SPV) system with a grid-connected inverter is analyzed by B M Kiran Kumar, M S Indira, and S Nagaraja Rao. Regarding the amount of components and boost factor, the outcomes are contrasted with the case of a conventional booster converter. The overall harmonic deformations of the output current in this investigation are reported to be 1.66%, which is within permitted international criteria [6].

The aim of the simulation model developed by Indian university researchers is to capture the maximum amount of power by comparing its features to those of commercial panels under varying temperature and radiation circumstances. The investigation was conducted using MATLAB/Simulink [7].

The authors, Benaissa O. M., Hadjeri S., and Zidi S. A., have adjusted the power work cycle in converters to enhance the obtained power, with the aim of optimizing the photovoltaic system's efficiency by decreasing network losses [8].

Photovoltaic systems must be installed at locations with the highest power in order to generate electricity with the greatest possible advantage. Because of this, three sophisticated approaches to the photovoltaic system can be used with MATLAB/SIMULINK: PSO, Perturb-and-Observe (P&O), and Incremental Conductance (I_C). Following analysis, the PSO offers better power capture, less loss, and less deformation than the other two techniques [9], [10].

The theme study "Photovoltaic based high-efficiency single-input multiple-output dc-dc converter" by J. Kondalaiah and I. Rahul relied mostly on the use of a dc-dc converter, several inductors, and a power switch to increase system efficiency and control the output voltage [11].

The PV system's performance and the definition of M.P.P. are impacted by the addition of a DC-DC boost converter. One of the most crucial components is the input capacitor, which for optimal performance requires half the output capacitor's capacity [12].

In-depth research on the idea of MPPT techniques—which greatly boost the solar PV system's efficiency—is performed by Shazly A. Mohamed and Montaser Abd El Sattar. In an effort to maximize the PV system's energy conversion efficiency, they offer a simulation-based comparison analysis of incremental conductance and perturb and observe methods [13].

In the crucial area of PV system optimization, Maximum Power Point Tracking (MPPT) controllers are receiving a lot of attention. The efficiency, performance, modernism, complexity, and tracking speed of these controllers vary, and they use different algorithms. Considering their quick improvement, MPPT controllers fall into two categories: traditional and advanced techniques [14].

During the year 2024, it is noted that our partners in the KALCEA project are using digital twin design platforms, which will increase public awareness and engagement in energy efficiency. One of them is the Expedite Digital Twin, which will be applied to a district in Riga, Latvia and will provide practical guidelines, algorithms and training materials to help other cities replicate digital twins for their districts, driving adoption wide range of sustainable energy practices [15].

The design of intelligent systems is a disciplinary work that requires the optimal selection of specified sensors, defined data from these devices, their processing and implementation based on IoT [16].

The results obtained from the studies show that the implementation of relevant educational and promotional policies can mitigate the growth rate of electricity consumption. [17].

A concise overview of the literature allows us to draw attention to the challenges and limitations of existing approaches of current techniques. While conventional methods are relatively easy to use, they are unable to distinguish between local and global peaks. As a result, their efficiency is minimal if partial shading happens. Because of their higher efficiency, advanced tracking techniques are frequently employed [18]. Hybrid approaches find a way to overcome the shortcomings of the individual conventional and sophisticated approaches. The best MPPT method selection is still a problem that needs to be resolved; this problem can be resolved by conducting a survey of the available approaches. A succinct categorization and assessment of some the used MPPT techniques is provided by this study. Moreover, this study offers a readily available reference.

III. Methodology

The usage of digital microcontrollers in this study has the goal of improving system efficiency, and the results can be applied in other research projects.

Unlike other research conducted by many authors, this study differs from previous research in that it establishes the parameters, both electrical and physical as well as the performance of the photovoltaic system using the P&O algorithm and a booster for each of the systems studied with controllers of different types for various value of the radiation and temperature. The study also compares the results obtained and highlights for researchers which of the controllers provides the highest efficiency in the work of photovoltaic systems, contributing directly to optimizing future-designed systems.

Through this paper will compare the performance of the photovoltaic system using the P&O algorithm, as well as examine the solar system for different irradiations and temperatures with a booster and two distinct types of controls (PD and PI type controllers).

In this research, we need to evaluate the benefits and drawbacks of every technique implemented in order to identify which approach will improve solar system performance generally for all users and specifically for UAMD.

These studies methods with the help of SIMULINK are suitable for study purposes by students who are studying in the field of RES in the Professional Studies Faculty and Information Technology Faculty at Aleksander Moisiu University of Durres. The system installed and its testing with controller of different types will be a case study for students during the design and simulation of SFV as for Albanian and Western Balkan' Universities in improving their performance.

The system will be simulated in several different states to enable and analyze in terms of improving the performance of the photovoltaic system. The schematic block has been added the buster (DC-DC converter), as well as the PI/PD controller, in order to increase the effectiveness of the photovoltaic system. Specifically, the system is tested to calculate parameters related to the maximum power point under optimal conditions, i.e. temperatures of 25 °C and solar radiation value 1000W/m2 in these cases:

- System includes a booster and PD controller with P&O algorithms.
- System includes a booster and PI controller with P&O algorithms.

The results will then be compared, concluding which of them offers the highest efficiency of the system. Researchers can change concrete values of radiation and temperature during simulation, depending on the specific geographic area and climate conditions.

The system with the proposed architecture utilizes algorithms optimization at the point with maximum power generated by PV systems. These algorithms manage voltage values to ensure that the system operates at the peak of the power-voltage curve. As algorithms for the capture of MPPT, perturb and observe (P&O) algorithms are used.

The complete scheme of connecting the photovoltaic system to the proposed architecture is shown in Fig. 2.

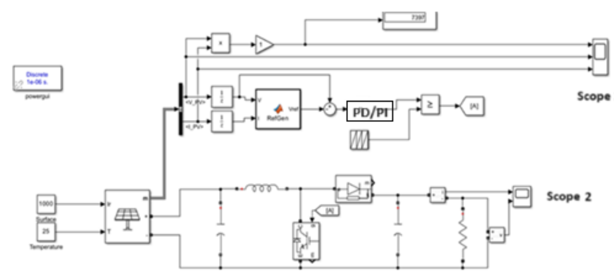


Fig. 2. The proposed architecture of the photovoltaic system.

In this scheme, these main blocks are used:

- Photovoltaic panel block
- Booster block
- PD/PI control block
- MATLAB Function block

Each of the blocks in the proposed architecture for the University of Durres will be highlighted in the sections that follow.

a) Photovoltaic panel block: The panels are selected SunPower Performances 5 UPP. The system has 18 monocrystalline panels, assembling with 10° tilt structures. This system has the installed power of 7.47 KWp. The surface area of the installed system is 46.5 m2, versus the area of the building of 649.3 m2, i.e. the area of the roof occupied from the modules is 7.16%. Coordinates of references: 41°06'35.2" N; 20°04'28.2" E.

The location, geographical position and dimensions of the installation space of photovoltaic panels are shown in Fig. 3.

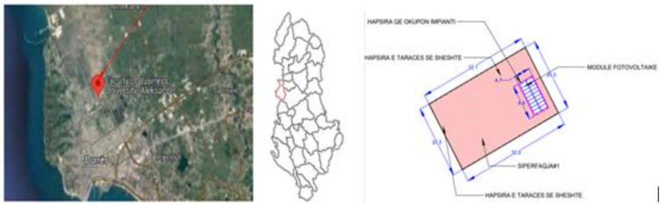
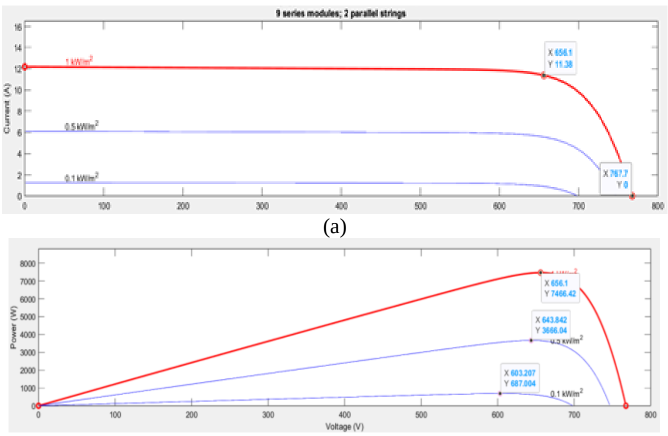


Fig. 3. Location and dimensions of the installation of photovoltaic panels.

Based on the data of the panels used in the photovoltaic system through the Matlab Code of P&O Algorithm, we can graphically determine the Volt-Ampere characteristic of nine panels connected in series in two parallel strings (Fig. 4a), as well as the characteristic where the point is clearly visible with maximum MPP power for different values of solar radiation (Fig. 4b).



(a)

(b)

Fig. 4. (a) Volt-Ampere characteristic of the used panels; (b) Determination of the maximum power point (MPP).

It is clear in Fig. 4(a) that the current passing through the used panels decreases with the decrease in the values of solar radiation referred to the same voltage values. Also from the volt-ampere characteristic it is noted that the current of the short-circuit (per V=0) decreases with the decrease of the values of solar radiation.

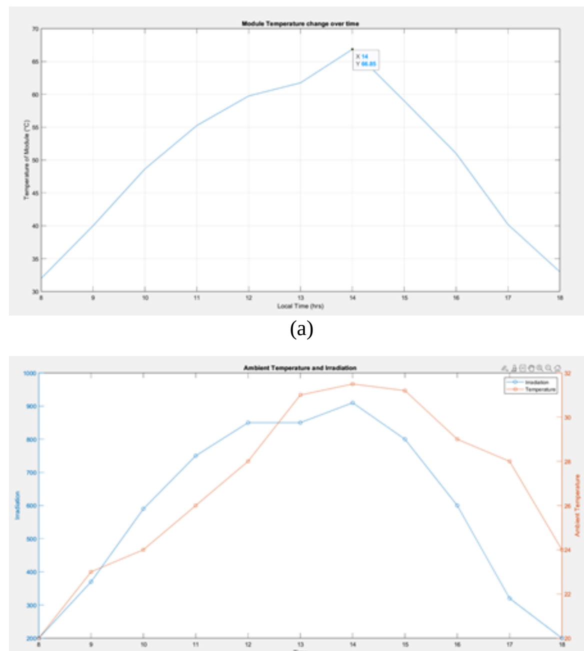
All the data obtained for the electric current, voltage and power of the system with photovoltaic panels for different values of solar radiation are summarized in the Table I:

TABLE I. DATA TABLE

Electrical and physical parameters	**Value of parameters**		
Solar radiation value (KW/m^2)	1	0.5	0.1
Maximum current value (A)	11.38	5.694	1.138
Maximum voltage value (V)	656.1	643.842	603.207
Maximum power value (KW)	7.466	3.666	0.687

Obviously from the above analysis, the maximum power value decreases with the decrease of the solar radiation value. This means that as the maximum power value decreases, the voltage and current values of the corresponding power values also decrease. In Fig. 4(b), it is seen that the maximum value of the reference voltage for the open circuit, that is, for I=0 A, the voltage value is 767.7 V, a value which also matches the data in the datasheet of the panels, where Open Circuit Voltage it is 85.3V for each of the panels; for the 9 panels connected in series, the open circuit voltage is 767.7 V, i.e. the same as the value determined graphically with the help of MATLAB SIMULINK.

During the study of the photovoltaic system, we can determine the temperature change of the modules, as well as the solar radiation for a time interval of 10 hours (8:00 a.m. - 6:00 p.m.) on a day in June. Fig. 5(a) shows graphically how the temperature of the module changes every hour of the specified time interval. With the help of MATLAB SIMULINK and the P&O algorithm, we can also determine the change in solar radiation in relation to the change in ambient temperature in each hour of the time interval studied, as in Fig. 5(b).



(a)

(b)

Fig. 5. (a) Module temperature change; (b) the change in solar radiation and ambient temperature for a certain time interval during a day in June.

As can be seen in Fig. 5(a), the panel's highest temperature is approximately 67ºC at 2:00 p.m. Conversely, Fig. 5(b) shows that solar radiation achieves its peak values at approximately 2:00 p.m., when the day's maximum temperature is approximately 32ºC.

The amount of sunshine and daytime temperature in June can be influenced by a variety of factors, including atmospheric conditions, geographic location, and June weather changes. Still, this is generally how it might appear on the midday. The solar radiation levels will progressively grow from low to moderate. The ambient temperature is warming when the sun gets stronger. During lunchtime the solar radiation peaks and receives the most amount of sunlight. Temperature range are warm to hot, with the greatest values of the day. Later in the afternoon the solar radiation will gradually decrease. The ambient temperature is still warm, but as the afternoon wears on, it begins to decrease.

b) Booster block: For the purpose of raising the input voltage, the booster block acts as a DC-DC converter. It is made up of multiple components, as shown in Fig. 6, including a cobbler, input capacitor, diode, MOSFET, shunt capacitor, and driving resistance. Since it stores energy and reduces deformations, the input capacitor is one of the most crucial components of the DC-DC converter [19]. Both continuous (CCM) and intermittent (DCM) modes of operation are available for this converter [20]. Managed by the controller, the work cycle determines the tension at the exit. At the booster's outlet are electric current and voltage measuring instruments, together with a scope (Scope 2) for observing the form, values, and boundaries of electrically enormous.

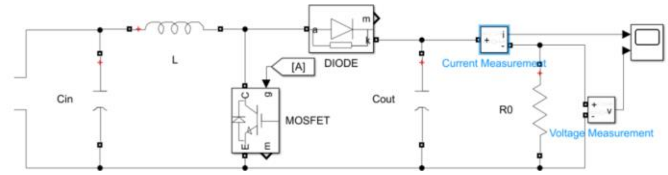


Fig. 6. Booster block, voltage & current measurement and the scope.

As the system's stability and efficiency rise, booster design and fundamental parameter selection play a critical role in enhancing system performance [21].

c) PID control block: PID control techniques are mostly used in the industry for the regulation of various physical processes. Control algorithms are found in terms proportional, derivative and integral [22], [23].

Proportional control is based on the difference between a given point and variable change, providing an immediate response [24].

Integral control is based on the accumulated error integral over time and reduces the stable state error by continuously stabilizing the output of the controller, thus eliminating the stable state errors or how else it is responsible for long-term reactions to changes in the signal of the input [25], [26].

Derivative control is based on measuring the rate of change of the error signal and regulating the output of the controller accordingly, thus improving the system's transitional response.

Each of the control types is specified by the corresponding coefficient, respectively Kp, Ki, Kd, which determine the controller's reaction force for each case. Their values must be tuned to improve the performance of the photovoltaic system. To connect a controller to photovoltaic systems, the other components are needed, which stabilizes the voltage and the current gained, thus preventing their fluctuations at the exit. Using of the controller ensures efficiency and security during energy generation. These control techniques can be combined by designing the PD (proportional-derivative), PI (proportional-integrative) controller or controller PID (proportional-Integrator-Derivative). In this paper we explain the role of PD/PI controllers in the performance of a photovoltaic system installed in Aleksander Moisiu University of Durres, as well as comparing their work.

d) MATLAB function block: With the help of this block, we design and analyze the photovoltaic system, as the most natural way of visualizing data and obtaining results through graphics. The codes used can be integrated with other languages, as well as adapted to much larger numbers of records, thus enjoying the properties of being scalar.

The technique used P&O (Perturb and Observe) serves to capture the maximum-powered MPPT point of the photovoltaic system. According to this method, the voltage at the exit of the photovoltaic system is adjusted by comparing the power value in the current period with that of the previous period. If the output voltage tends to increase, the control system tends to reduce it in order to keep it at stable power values at the exit.

Algorithm flowchart is shown below in Fig. 7:

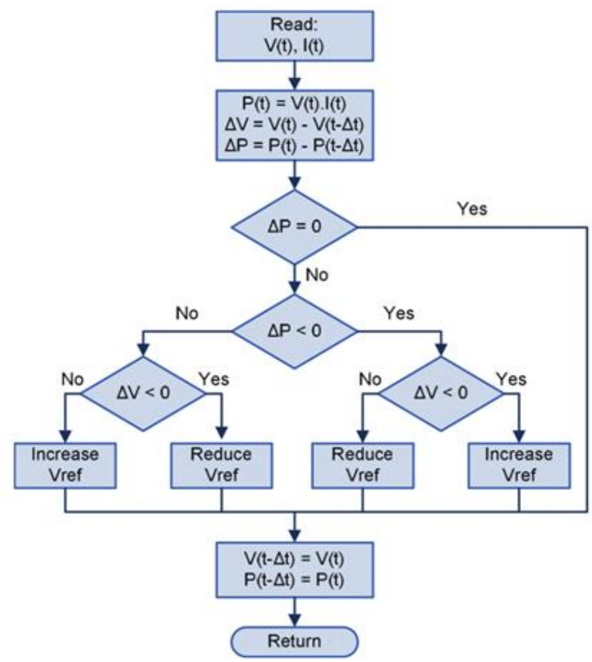


Fig. 7. P&O Algorithm flowchart [27].

IV. Results

To analyze the performance of the photovoltaic system with different types of control, we must follow the following steps:

- Select the type of controller and its parameters
- Identify the scheme
- I/O give out the details
- Stimulate
- Simulation executed

During the simulation, the temperature (25°C) and radiation (1000W/m^2) parameters are set. The researcher can modify the tracks as needed.

- Simulation of the photovoltaic system with Proportional Derivative (PD) controller

Firstly, after choosing the type of PD controller (Fig. 8), we connect photovoltaic system with the controller and follow the above-mentioned path.

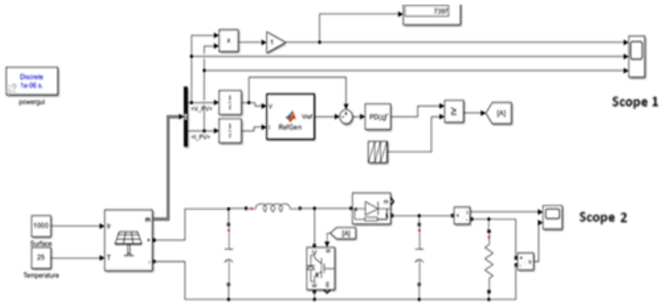


Fig. 8. Block scheme with PD controller.

In Scope 1 screen we can clearly distinguish the change of power, voltage and current in relation to the time for the system with the PD controller connected to it, while on the screen of the Scope 2 the flows of the current and voltage at the exit of the booster will appear.

The output views of scope 1 are for the initial moments of simulation of the photovoltaic system with PD controller (Fig. 9):

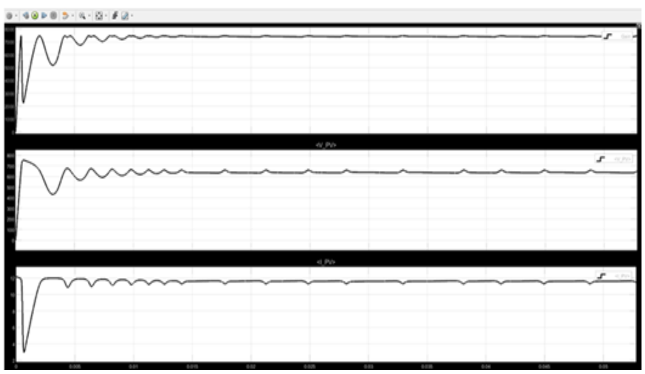


Fig. 9. The view of the oscilloscope 1 in the initial moments.

It is clear that at the initial moments of the waves last about 14 ms. The parameters (power, voltage, current) then start stabilizing, so the view of the oscilloscope 1 in the stabilized moments is shown in the Fig. 10.

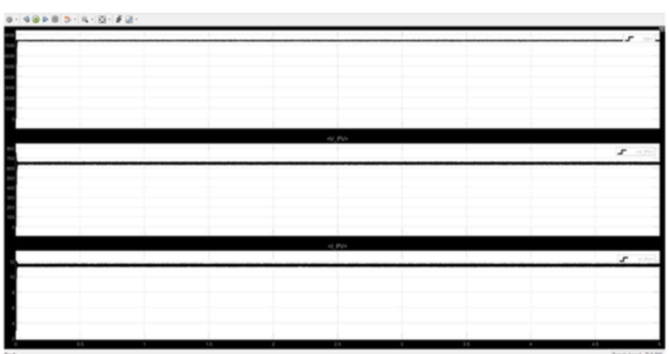


Fig. 10. Stabilized current values, voltage and power in case of PD controller scheme.

It is clear that the stabilized parameters are: power of about 7.47 KW, current value about 11.5 A, while voltage value is about 650 V.

The increase of the continuous voltage value with booster assistance from 650V to about 800V, affects the decrease of the current value from 11.5A to 9.3 A. This process is accompanied by significant variations in values, such as Fig. 11. Specifically:

Fig. 11. Fluctuations of current and voltage values at the exit of the booster in the PD controller scheme.

These fluctuations around average values exceed 5% of tolerance in terms of the range of deformations, so although the maximum power value is 7.47 KW. Current values fluctuate from (7.5-10) A, while voltage values from (650-870) V.

In this case the system is not considered in optimal working conditions for obtaining maximum power, for the maximum efficiency of the system.

- Simulation of the photovoltaic system with the Integral Proportional Controller (PI), as is shown in Fig. 12.

By including a PI controller in the suggested architecture of the photovoltaic system, the simulation of the scheme will be improved. Its operation, which is based on the average error of the integral over time, reduces the stable state error by consistently stabilizing the controller's output and therefore eliminating of the stable state errors. In other words, it can be held responsible for its long-term responses to changes in the input signal [28].

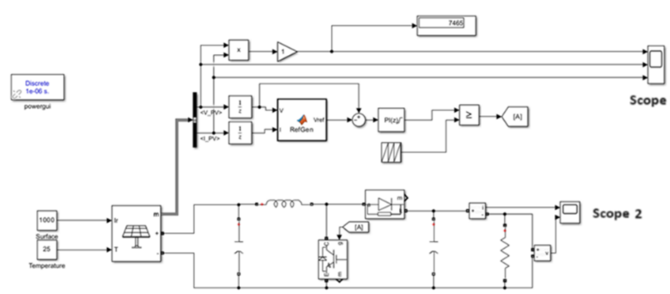


Fig. 12. Block scheme with PI controller.

The output views of scope 1 are for the initial moments of simulation of the photovoltaic system with PI controller (Fig. 13):

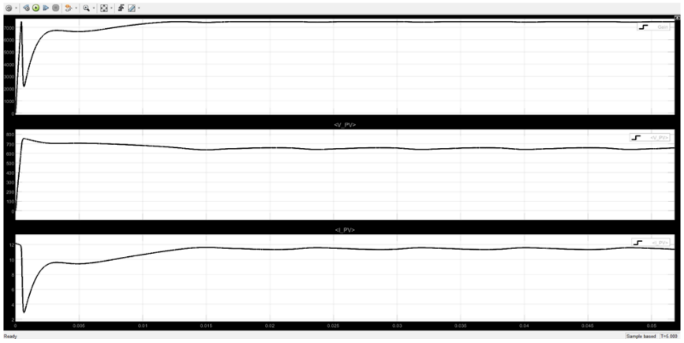


Fig. 13. The view of the oscilloscope 1 in the initial moments.

- As seen the largest leaches occur until the first 4ms, then the flow of variability drops significantly.

The current, voltage and power begin to stabilize, as shown in Fig. 14.

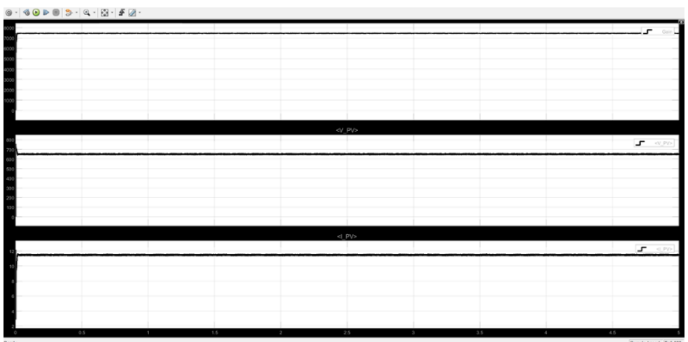


Fig. 14. Stabilized current values, voltage and power in case of PI controller scheme.

At the initial moment, the fluctuations are observed, which have a smaller duration than in the first instance until achieving the desired stable value. Stabilization time for the PI controller is 14 ms in the frame with the PD controller. At this moment the Update block command is given.

At the exit of the booster, the voltage and the current have the values around the average value below 5% of the average value, Current values fluctuate from (8.6 – 9.5) A, while voltage values from (770 - 805) V. The stabilization time is about 14 ms (Fig. 15), as well as in the system with PD controller. Obviously the deformations are more acceptable in the case of the PI controller scheme than in the system with the PD controller.

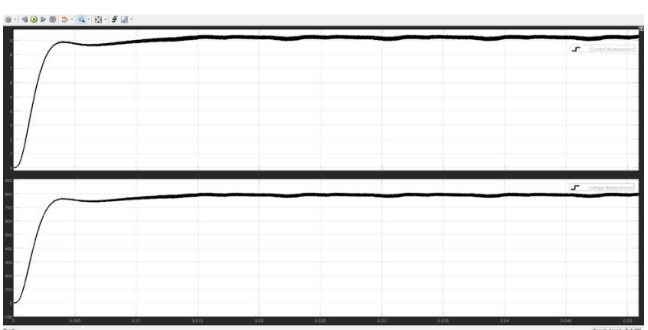
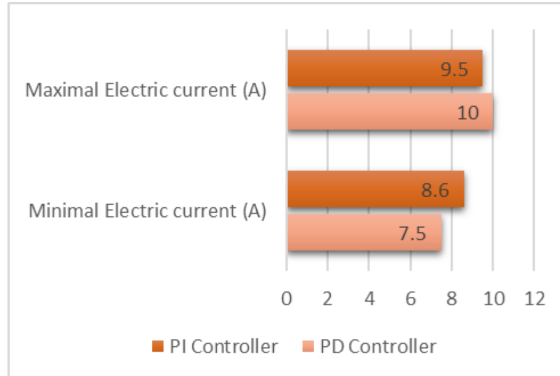
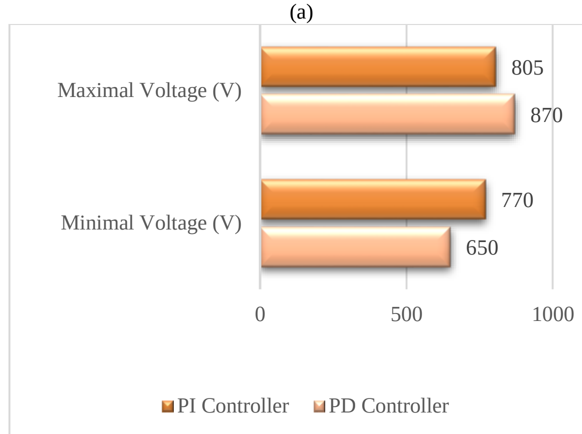


Fig. 15. Fluctuations of current and voltage values at the exit of the booster in the PI controller scheme.

Finally, we can compare the performance of systems with different types of controllers by summarizing the data for electrical quantities in the Fig. 16:



(a)



(b)

Fig. 16. Change rate of (a) current, (b) voltage for different controllers.

If we refer to the voltage and current variation limits for each of the controller types, we can obtain the results shown in the graph below (Fig. 17).

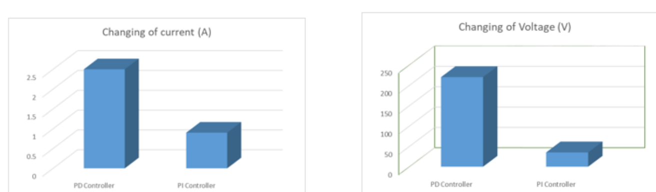


Fig. 17. The variation limits of current, voltage and time for the PD/PI controllers.

V. Discussion

Obviously, the changes in current and voltage at the output of the amplifier for the system with PI controller are smaller than for the one with PD controller. Also, the stabilization time of the power, current, voltage is almost the same in the PI controller system with the stabilization time of these electrical parameters at the output of the PD controller system.

So it is worth noting that in the conditions of the photovoltaic system with PI controller, the current and voltage fluctuations at the output of the booster are within the allowed values of 5% compared to the case of the system with PD controller.

Ultimately, installing a PI controller precisely on the photovoltaic system can improve its performance, not just at the University of Durres but also in other situations.

The developed analysis guides the researchers about the more efficient use of photovoltaic systems with the help of the booster, controller and performance improvement algorithms of these renewable energy systems [29], [30]. Improving the performance of photovoltaic systems with the help of the above methods leads to the capture of the point with maximum power in minimum time intervals [31].

The studies demonstrate the global power market's rapid expansion based on the evaluation of data at the worldwide level, data history across time, and contemporary analysis. By 2026, it is anticipated that installed energy storage capacity worldwide would exceed 270 GW [32]. The primary cause is the increasing demand for renewable energy systems' flexibility and storage in energy systems [33].

The methods that have been established until now will expand the applications of current renewable energy technologies with artificial intelligence support [34]. Their foundation is a zero-carbon economy. Renewable energy is a key technology for achieving carbon-free energy transitions [35].

The RES faced new chances and challenges during the Covid-19 crisis, but they remained a powerful resource [36]. For this reason, it is necessary to develop detailed market analyses and forecasts [37], [38].

So researchers should explore key industry challenges and identifying obstacles, to optimize renewable energy systems in order to accelerate the development of a low-carbon economy [39], [40].

VI. Future Work

We recommend that scientific researchers should continue to experiment the operation of photovoltaic systems with other types of controllers to take further steps forward in improving their performance. They should also improve optimization algorithms to increase energy efficiency. Lecturers should implement the optimization methods to the university education process.

VII. Conclusion

Researchers attempt to forecast and analyze a country's or region's energy performance based on various scenarios by utilizing modular components. Together with real-time data on energy generated by renewable sources, these components provide environmental visualization. The results can then be improved, evaluated and compared in order to arrive at the most efficient decision-making.

In order to improve the photovoltaic systems' efficiency, we can add a booster to the photovoltaic systems. This booster will raise the continuous voltage while maintaining the 7.47 KWp installed power and will also allow us to modify the stabilized output voltage values when they start to fluctuate for any reason. For this reason, we use P&O optimization algorithms for capturing the MPP, determining the values of electrical parameters (current, voltage) for different values of solar radiation; as well as for determining the physical parameters (temperature, solar radiation) of the panels within a certain time interval on a given day. Also with the help of optimization methods we can increase the performance of the photovoltaic system experimenting with different types of controllers. The developed analysis showed that the stabilization time of the voltage, current and output power is the same for the both controllers (PI/PD). Regarding the change of electrical quantities, the current fluctuates 36% less in the scheme with PI controller compared to that with PD controller, while the voltage changes around 29.2% less in the scheme with PI controller.

These results related to the performance of the photovoltaic system for the capture of MPPT with the help of the booster, controller and optimization algorithms will serve to modernize the curricula with contemporary methods that influence on the sustainable development towards a green society and economy. Also this study will serve scientific researchers, as well as all stakeholders for improving the work of systems installed as well as the design of new systems in the University of Durres and the Western Balkan Universities.

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