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4. POWER ENGINEERING AND ENERGY EFFICIENCY

INCREASING THE EFFICIENCY OF AN AUTONOMOUS POWER SUPPLY SYSTEM BASED ON PHOTOELECTRIC CONVERTERS

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Abstract. *The scientific work consists of an explanatory note. Explanatory note: 15 pages, 14 figures, 6 tables, list of references from 14 sources. The object of research – control systems for energy parameters of photovoltaic converters.*

The subject of research – means to increase the efficiency of control systems for energy parameters of photovoltaic converters.

The introduction contains a general justification of the relevance of the work, consideration of the basic control algorithms for photovoltaic converters to select the maximum power, definition of the purpose and tasks of work. The second section is devoted to the theoretical issues that include the types of solar modules, analysis of their main differences and limits of their application, the role and place of solar energy today. The object for further work was determined as a result of this analysis. The third section is devoted to preparation for system modeling and selection of elements. The fourth section presents the results of this system.

Keywords: *solar electric power, photoelectric converters, energy parameters, work efficiency, algorithms for monitoring maximum power, incremental conductivity algorithm.*

I. INTRODUCTION

It is known that the main disadvantage of traditional energy sources is the negative impact on the environment, and sources are limited in time. It is necessary to find an alternative to this problem given the economic crisis in Ukraine. We need to find ways to increase the efficiency of autonomous power supply systems or improve existing ones. One of the fastest growing sectors of alternative energy is solar energy.

Several methods are used to generate electricity. The most promising is the method of direct conversion of radiation into electricity using solar panels.

Each complete set of the solar battery has the device allowing to regulate energy expenses and procedure of its accumulation. This device is called a charge controller. Currently, there are many controllers, but this study considered MRRT controllers, which allow more full use of the potential of solar panels and as a result receive 15-30% more electricity compared to other controllers.

The purpose of the work is to obtain a quantitative analysis of the influence of the algorithms for finding the maximum power point on the efficiency of the power supply system based on photovoltaic converters.

Tasks:

1. Consider means of ensuring the efficiency of the system based on photovoltaic converters.
2. Create a model of the power supply system, which includes a photovoltaic converter, a step-down DC converter and other necessary elements. Consider in detail the analytical dependences and parameters of all elements.
3. Conduct a study of the developed system by modeling in Matlab and build the main characteristics of the system.

The object of research is the control systems for the energy parameters of photovoltaic converters.

The subject of research is the means of increasing the efficiency of control systems for energy parameters of photovoltaic converters.

Research methods are monitoring and analytical evaluation of electromagnetic processes in the power supply system, the method of simulation and comprehensive evaluation of the efficiency of the power supply system.

II. LITERATURE ANALYSIS

2.1 Power supply systems based on photovoltaic converters

Several methods are used to generate solar electricity. The most promising is the method of direct conversion of radiation into electrical energy using photoelectric converters (electrical installation that generates current by this method is shown in Figure 2.1).

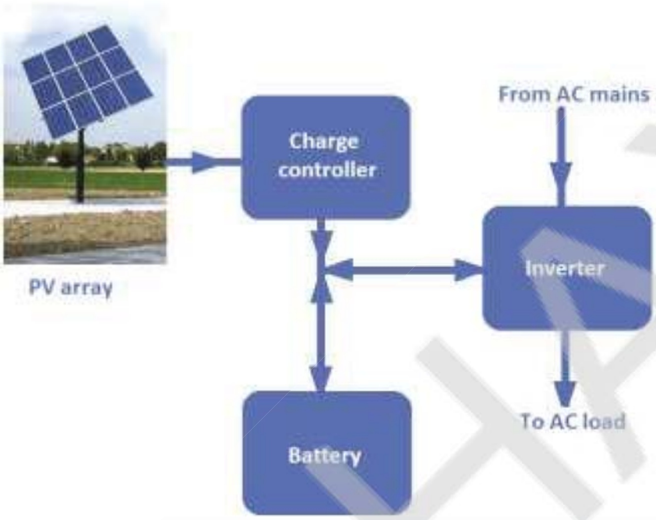


Figure 2.1 – The principle of operation of a solar installation

Currently, the record for the efficiency of solar cells is 47%, which was achieved with the help of multi-circuit concentrator solar cells. In mass photovoltaic panels, the efficiency is approximately 17-20% [1]. However, the actual efficiency of photovoltaic conversion depends on the algorithms of the controllers, which match the load parameters with the energy parameters of the photovoltaic panel.

Photovoltaic cells can be represented as a functional unit with external, internal and output parameters (Figure 2.2).

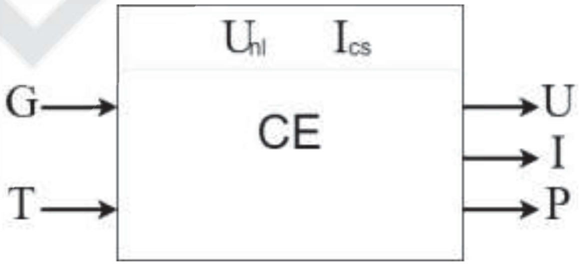


Figure 2.2 – Photoelectric element in the form of a functional unit

The external parameters include: light (G), temperature (T). The internal parameters include: no-load voltage (U_{nl}), short-circuit current (I_{sc}). Output parameters are output voltage (U), load current (I) and output power (P) [2].

The main characteristic of photoelectric converters is the I-V curve – the relationship between load current and voltage at the terminals of photoelectric converters at constant values of temperature and intensity of solar radiation.

The intensity of solar radiation and temperature are important factors in determining the I – V characteristics. The photoelectric converter is represented by a Solar Cell unit in the MatLab software package (Figure 2.3).

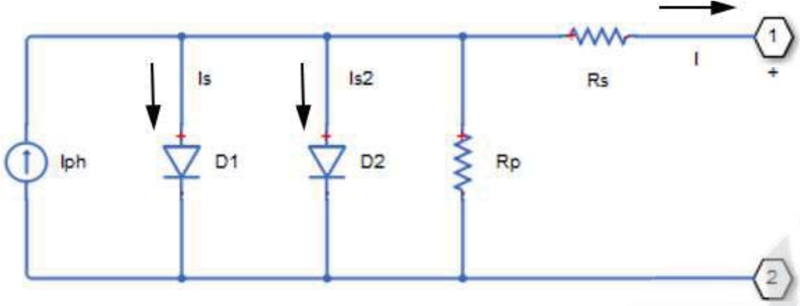


Figure 2.3 – Equivalent circuit of the Solar Cell unit

The output current I is determined by the equation:

$$I_d = I_{ph} - I_S \left[e^{\left(\frac{V+I\cdot R_S}{N\cdot V_t}\right)} - 1 \right] - I_{S2} \left[e^{\left(\frac{V+I\cdot R_S}{N_2\cdot V_t}\right)} - 1 \right] - \frac{V + I\cdot R_S}{R_p} \qquad (2.1)$$

where I_{ph} – photo-inductive current:

$$I_{ph} = I_{ph0} \cdot \frac{I_r}{I_{r0}}, \qquad (2.2)$$

where I_r – radiation (light intensity) in W / m², which falls on one element; I_{ph0} – measured current under illumination I_{r0}; I_s – saturation current of the first diode; I_{s2} – the saturation current of the second diode; V_t – thermal voltage; N_1 – the quality factor of the first diode; N_2 – the quality factor of the second diode; V – voltage on the solar battery [3].

The unit provides a choice between two models:

1. 8-parameter model, where the previous equation describes the output current;
2. 5-parameter model, which simplifies the equation: the saturation current of the second diode is zero, the resistance of the parallel resistor is infinite.

You can simulate any number of solar cells connected in series using a Solar unit by setting the "Number of series cells" to a value greater than 1.

You need to make multiple copies of the unit files to connect the solar units in parallel, where each unit contains several cells in series.

Selection of methods for the parameterization unit:

1. By s / c current and o / c voltage, 5 parameter: providing voltage and current of open short circuit.
2. By equivalent circuit parameters, 5 parameter / 8 parameter: providing electrical parameters of the equivalent circuit of the solar cell model using the 5-parameter / 8-parameter model.

Current flowing during a short circuit of a solar cell: this value is available only when selected by s / c current and o / c voltage, 5 parameter.

Solar voltage, idling: this parameter is available only when selected by s / c current and o / c voltage, 5 parameter.

Diode saturation current IS: this value is available only when selecting one of the following parameters: by equivalent circuit parameters, 5 parameter; by equivalent circuit parameters, 8 parameter.

Saturation current of the second diode $\mathrm{I_{s2}}$: this value is available only when selected by equivalent circuit parameters, 8 parameter.

Solar-generated current $\mathrm{I_{ph0}}$ when the radiation intensity is $\mathrm{I_{r0}}$. This value is available only when selecting one of the following parameters: by equivalent circuit parameters, 5 parameter / 8 parameter.

Other parameters: Irradiance (light level), $\mathrm{I_{r0}}$; Quality factor, N; Internal series resistance, R_s; Internal parallel resistance, R_p [3].

2.2 Algorithms of MRRT controller

There are several basic algorithms for finding the maximum power point. The most common MPPT algorithms are: perturb and observe method; incremental conductance method and constant voltage (current) method.

Perturb and observe method

This algorithm works by periodically perturbing (increasing or decreasing) the voltage or current of the array, comparing the output power of the array with that of the previous perturbation. If the perturbation in the final voltage leads to an increase in power, the perturbation must be maintained in the same direction, otherwise – the perturbation changes in another direction. The cycle of perturbations is repeated until the maximum power is reached at ($\Delta P = 0$).

The advantages of this method are ease of implementation, no need to know the preliminary values of the array of photovoltaic converters [5, 7]. The algorithm does not stop perturbing when the point of maximum power is reached, oscillations occur around it, which leads to some power losses [8].

Incremental conductivity algorithm

The basis of this algorithm is that the derivative of the output power of the array of photovoltaic converters relative to the output voltage is zero ($\frac{dP}{dU} = 0$), at any level of radiation and temperature. It is negative to the right of the maximum power point (MPP) and positive to the left of this point, as shown in Figure 2.4.

$$\begin{aligned} dP/dU &= 0 \text{ in MPP} \\ dP/dU &< 0 \text{ right of MPP} \\ dP/dU &> 0 \text{ left of MPP} \end{aligned} \tag{2.9}$$

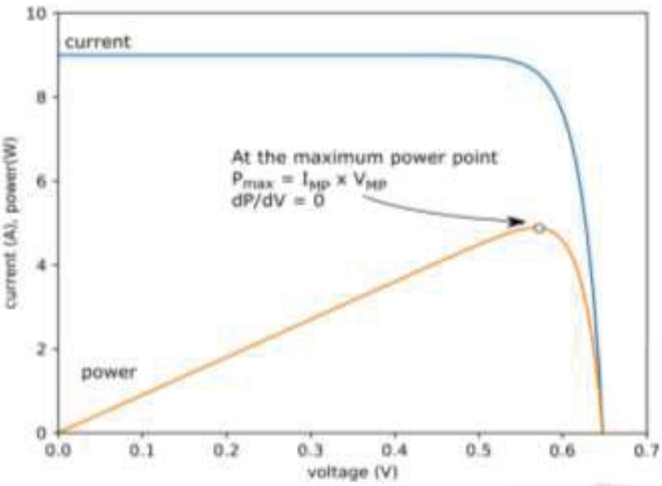


Figure 2.4 – Power derivative of voltage

The block diagram (Figure 2.5) shows that MPP is achieved when the instantaneous conductivity (I/U) is equal to the incremental ($\Delta I/\Delta U$). Once the MPP is reached, the array continues to operate at this point until the change is measured. This change will correlate with the change in the state of the atmosphere and the actual value of the MPP.

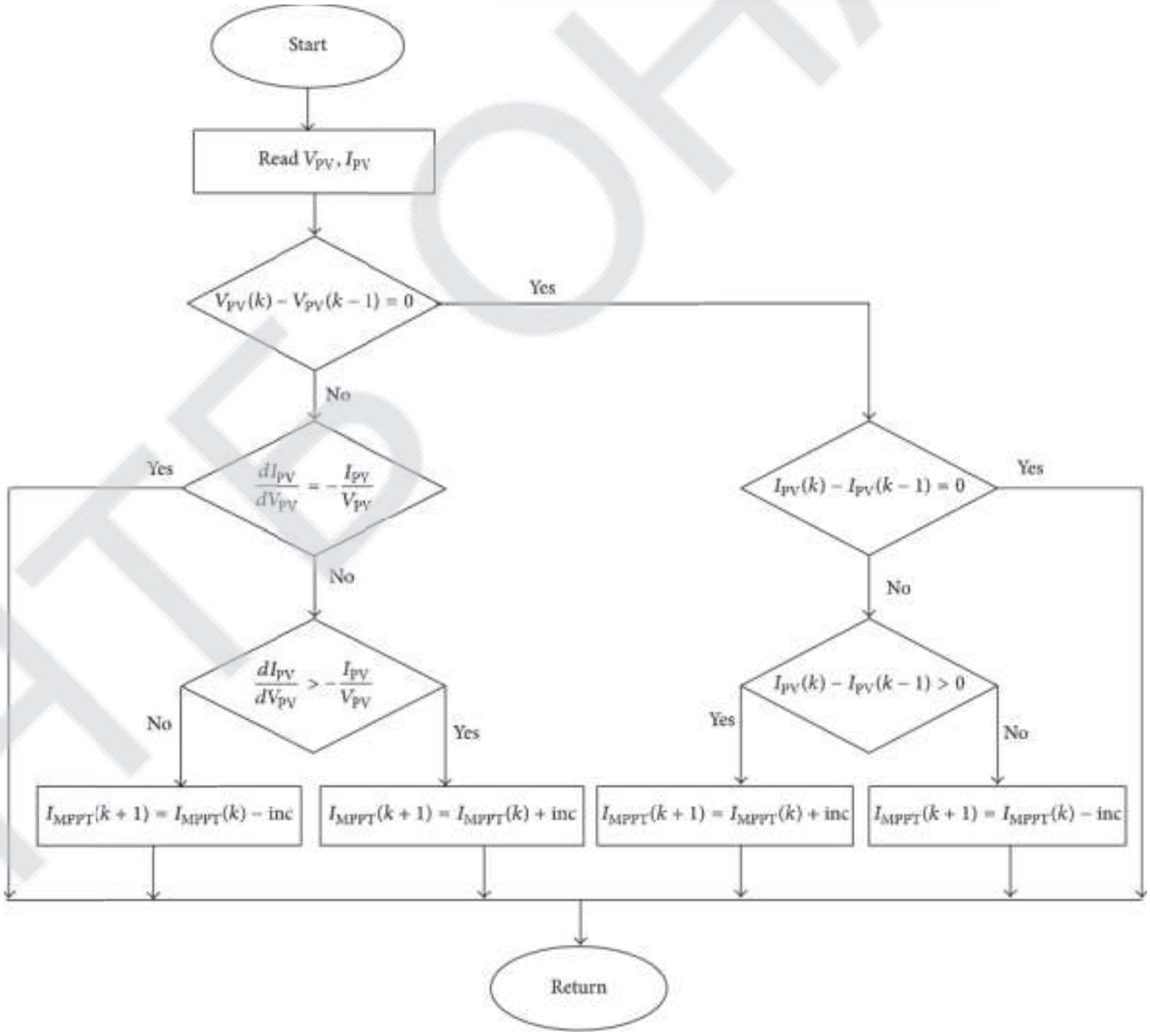


Figure 2.5 – Block diagram of the incremental conductivity algorithm

When $\Delta I/\Delta U < -I/U$ the algorithm is running to the right of the MPP, then the operating voltage of the array is reduced to move the operating point towards the TMP. When $\Delta I/\Delta U > -I/U$ the algorithm runs to the left of the MPP, then the operating voltage increases. The operating voltage of the array does not require changes after MPP $\Delta I/\Delta U = -I/U$ [6, 9].

This method has the advantage of no oscillations around the MPP in stationary conditions. Also, the method is not stable during transient conditions [4,11].

DC voltage algorithm

The simplest of the known MPPT algorithms is the DC voltage method. It is based on the value of the open circuit voltage. In this method, the feedback U is compared to a fixed reference voltage, and the resulting signal regulates the duty cycle of the DC- DC converter to maintain the operating point of the array in the MPP, Figure 2.6.

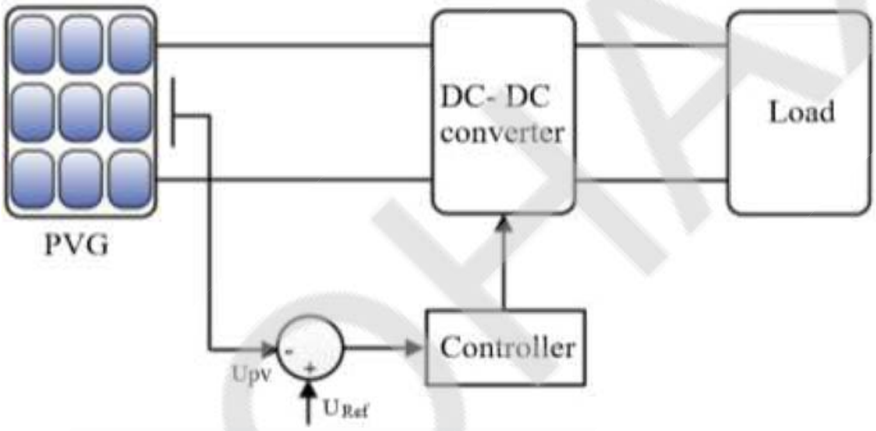


Figure 2.6 – Scheme of the method with a reference signal of direct voltage

This algorithm (Figure 2.7) is simple and economical, requiring only one feedback equation [10].

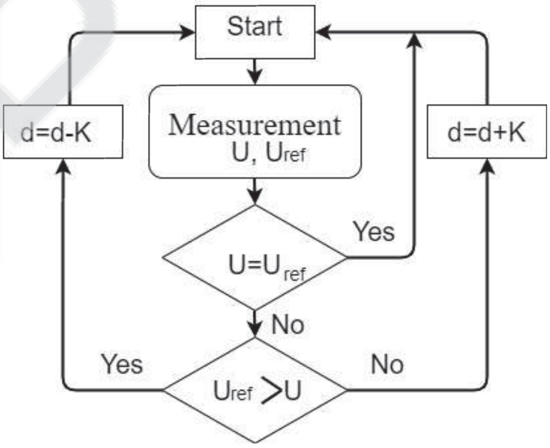


Figure 2.7 – Block diagram of the DC voltage algorithm

The next section presents the simulation results in the MatLab package of the considered algorithms.

III. MODELING AND ANALYSIS OF RESULTS

3.1 System model with incremental conductivity algorithm

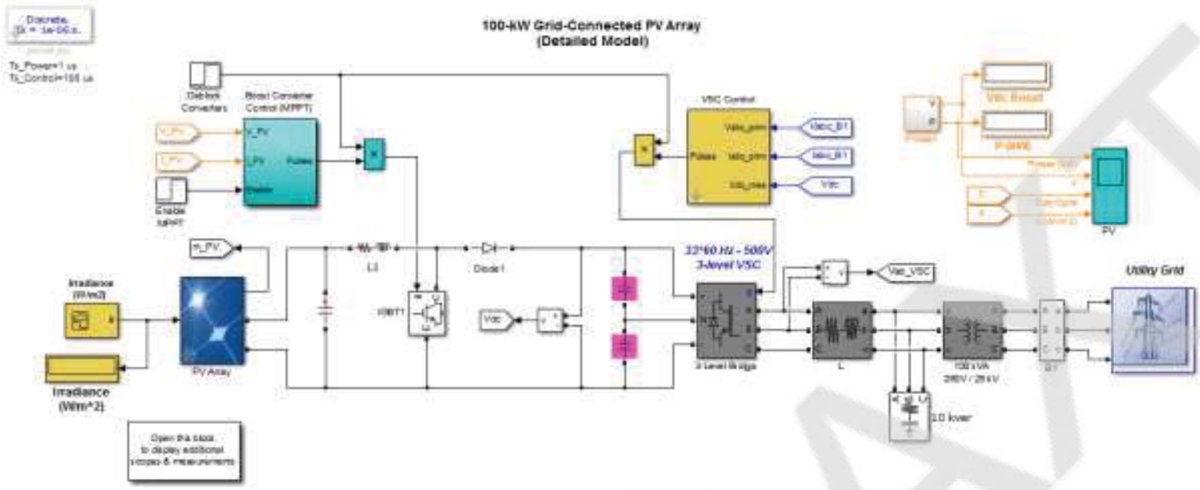


Figure 3.1 – System model with incremental conductivity algorithm

Table 3.1 – The main parameters of the system model with an incremental conductivity algorithm

№	Bloc	Parameter
1	PV array	Number of serial cameras 96; Voltage 64.2 V; Short circuit current 5.96 A; Voltage and current at maximum power: 54.7 V, 5.58 A
2	VSC Control	Rated power $100 \cdot 10^3$ W; Frequency 60 Hz; Rated voltage at alternating current of 500 V
3	Utility Grid	5 km line: 3 phases, frequency 50 Hz; Active power 2 MW; Transformer: Rated voltage 25 kV; Rated capacity 100 MW; Frequency 50 Hz
4	L	Active resistance 2 mOhm; Inductance 260 μH
5	10 kvar	Rated voltage 260 V; Rated frequency 50 Hz; Active power 1000 watts
6	IGBT1	Resistance 0.001 Ohm; Inductance 0 Gn
7	C	Capacity $12000 \cdot 10^{-6}$ F
8	Diode	Resistance 10 mOhm
9	L1	Resistance 0.005 Ohm; Inductance 5 m Gn
10	10 kVA 260 V/ 25kV	Power 100 kW; Frequency 60 Hz; Magnetized resistance 500 Ohms
11	3-Level Bridge	Internal resistance of the source is 0.002 Ohm; The inductance is 250 μ Gn
12		System sampling time 100 μs; System frequency 50 Hz

This model (Figure 3.1) includes:

1. An array of photoelectric converters with a maximum power of 100.7 kW when illuminated by solar radiation of 1000 W / m².

2. Converter that increases the voltage from 273.5 V to 500 V.

3. The duty cycle switching is optimized by the MPPT controller, which uses the "Incremental Conductivity" algorithm.

4. 3-level 3-phase voltage converter (VSC). The VSC converts 500 V DC to 260 V AC and retains the power factor.

5. Three-phase transformers and loads.

6. Network model of 25 kV switchgear and equivalent 120 kV system.

Let's analyze the system modeling using the incremental conductivity algorithm, the result is presented in Figure 3.2.

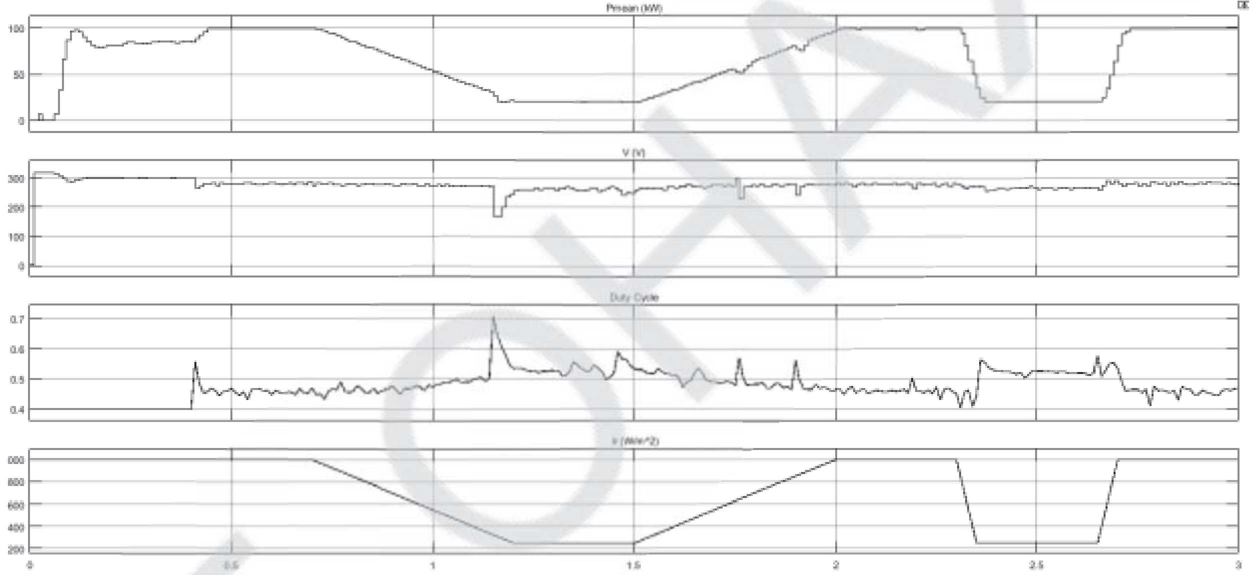


Figure 3.2 – The results of modeling using the algorithm

From t = 0 s to t = 0.05 s, the pulses to the Boost and VSC converters are blocked. The three-level bridge works as a diode rectifier, and DC capacitors are charged above 500 V.

At t = 0.05 s, the Boost and VSC transducers are released. The power of the DC circuit is regulated at an increase of up to 500 V. At 0.45 s of the power value of 99.86 kW, MRRT begins its work, the regulator increases the supply voltage, changing the duty cycle to obtain maximum power. The duty cycle at this time is 0.46, the illumination reaches 1000 W/m². At 0.5 s, the maximum power is reached at 100.3 kW, when the duty cycle is equal to D = 0.465, the resulting voltage of the module is 276.9 V.

From t = 0.7 s to t = 1.2 s, the illumination of solar radiation decreases from 1000 W/m² to 250 W/m². MPPT continues to monitor maximum power. At t = 1.4 s, when the illumination is equal to 250 W / m², the duty cycle is equal to D = 0.54. Accordingly, the voltage is 248.5 V and the power is 21.80 kW. From t = 1.5 s to t = 2 s, the illumination increases again to the value of 1000 W/m². Power at 2 s reaches 98.5 kW, voltage is 283.6 V, duty cycle is 0.47. Therefore, it can be concluded that MPPT continues to monitor the maximum power during a rapid change of illumination.

The initial parameters when the incremental conductivity algorithm is included in the system are shown in table 3.2.

Table 3.2 – The resulting system parameters

№	Illumination, W/m2	Voltage, V	Power, kW
1	1000	281,5	100,3
2	600	277,8	55,15
3	250	248,5	21,80

Let's analyze the system modeling without using the incremental conductivity algorithm, the result is presented in Figure 3.3.

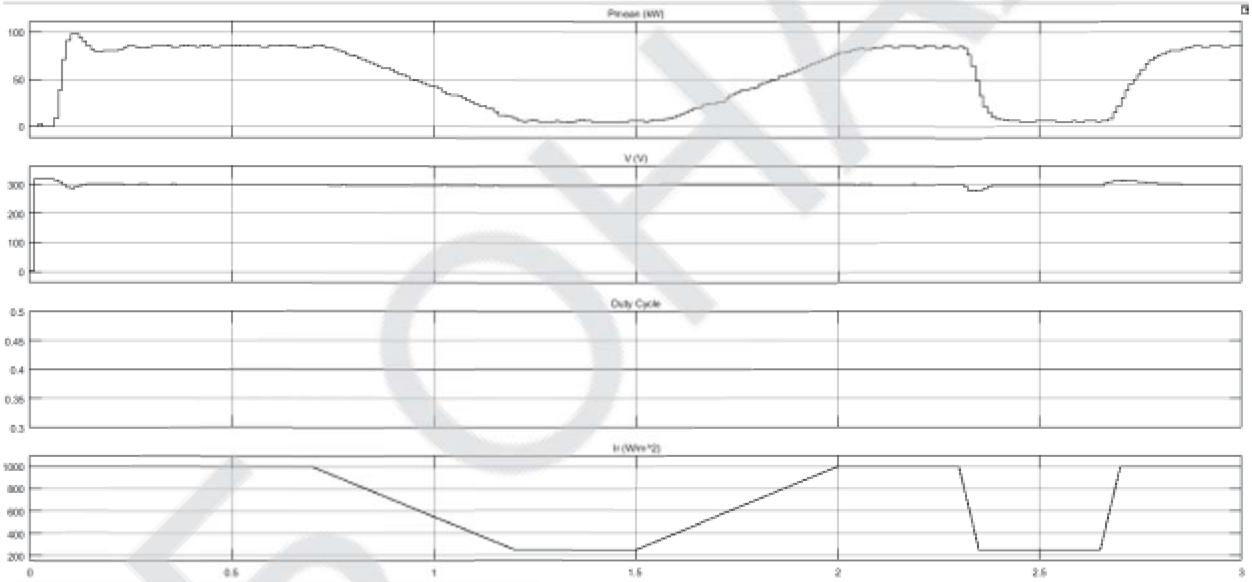


Figure 3.3 – Initial parameters of the system without using the algorithm

From t = 0 s to t = 0.05 s, the pulses to the Boost and VSC converters are blocked. The three-level bridge works as a diode rectifier, and DC capacitors are charged above 500 V.

At t = 0.05 s, the Boost and VSC transducers are released. The power of the DC circuit is regulated at an increase of up to 500 V. At 0.5 s, the duty cycle is equal to D=0.4, and the illumination reaches 1000 W/m². Maximum power 85.08 kW, the average voltage of the PV module is 300.8 V.

From t = 0.7 s to t = 1.2 s, the illumination of solar radiation decreases from 1000 W/m² to 250 W/m². At t = 1.4 s, when the illumination is 250 W/m², the voltage is 298.4 V and the power is 5.49 kW.

The output parameters with the algorithm of incremental conductivity in the system are listed in table 3.3.

Table 3.3 – The resulting system parameters

№	Illumination, W/m^2	Voltage, V	Power, kW
1	1000	300,8	85,08
2	600	303,7	33,17
3	250	298,4	5,49

Therefore, we can conclude that the operation of the algorithm achieves the maximum power of the module. The power is equal to 100.3 kW (the point of maximum power is 100.7 kW) at illumination of 1000 W/m² under the action of the MRRT algorithm. Whereas when the algorithm is turned off, the power in this light is 85.08 kW. Power under the incremental conductivity algorithm increased by 17.6%. The power increased 4 times at illumination of 250 W/m².

3.2 Determining the quality of the output parameters of system models

The quality indicators of output voltages and currents were analyzed with the MRRT algorithm on and off. It was necessary to measure the output parameters of the system (signals to the network), the output of the VSC, the output of the load using current and voltage meters to ensure this analysis. The results of the output current and voltage of the entire system using the algorithm are shown in Figure 3.4. Figure 3.5 shows the output data without using the algorithm.

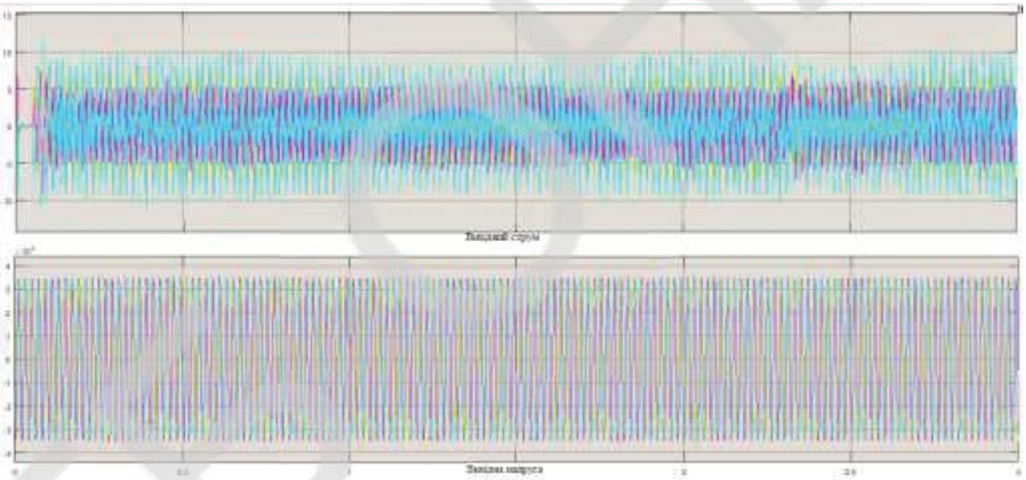


Figure 3.4 – Output currents and voltages of the system with MRRT

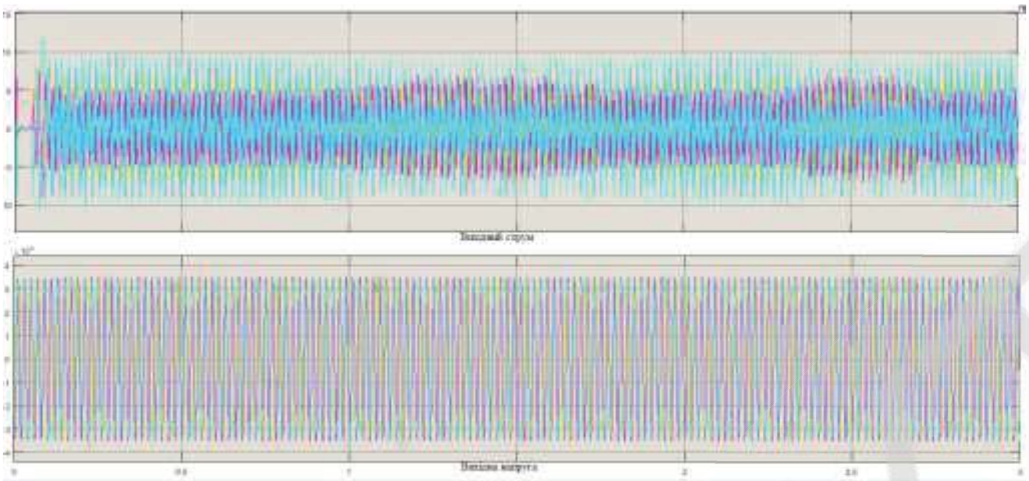


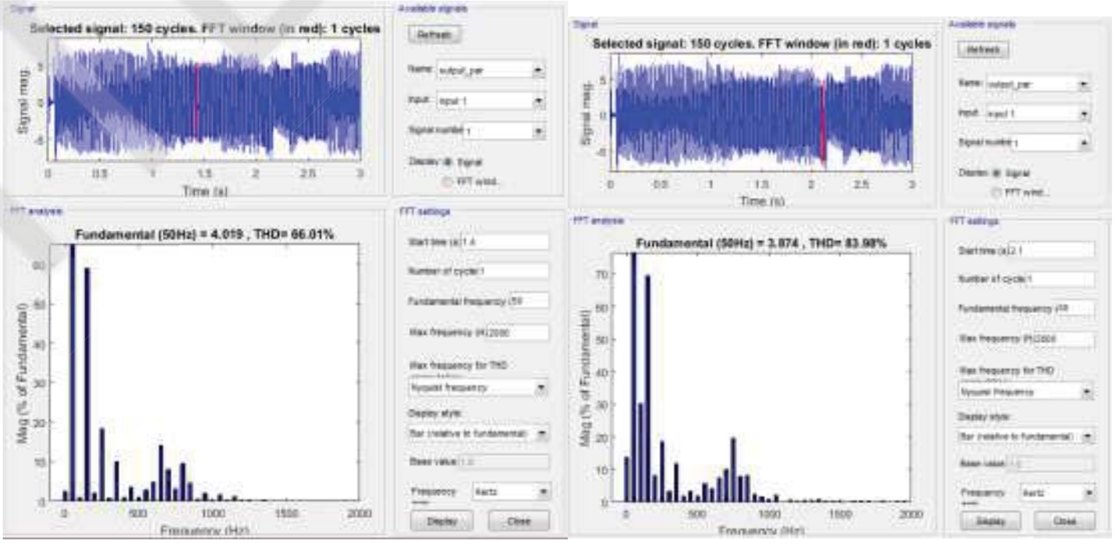
Figure 3.5 – Output parameters of the system without using the algorithm

Table 3.4 shows the results of quality assessment (FFT Analysis) of parameters at different points of the system using the incremental conductivity algorithm.

Table 3.4 – Quality parameters of the output currents

Type of THD	Output current quality,%	Sampling time, p	Lighting, W/m2
From the network	66,01	1,4	250
	62,91	1,7	600
	83,98	2,1	1000
From the converter	72,54	1,4	250
	74,88	1,7	600
	78,26	2,1	1000
From the load	87,32	1,4	250
	55,24	1,7	600
	58,06	2,1	1000

Figure 3.6 shows the results of the analysis of THD mains current for a system with an algorithm at different time intervals and illuminance.



Selected signal: 150 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 4.019 , THD= 66.01%

Selected signal: 150 cycles. FFT window (in red): 1 cycles

Fundamental (50Hz) = 3.874 , THD= 83.98%

Figure 3.6 – Results of THD current with the algorithm

Table 3.5 shows the results of the evaluation of the quality of parameters at different points of the system without the use of the incremental conductivity algorithm.

Table 3.5 – Quality parameters of the output currents without the use of the algorithm

Type of THD	Output current quality,%	Sampling time, p	Lighting, W/m2
From the network	60,15	1,4	250
	77,92	1,7	600
	84,36	2,1	1000
From the converter	69,63	1,4	250
	66,20	1,7	600
	54,89	2,1	1000
From the load	77,62	1,4	250
	57,22	1,7	600
	53,20	2,1	1000

Figure 3.7 shows the results of THD analysis of the mains current for the system without using the algorithm at different time intervals and illuminance.

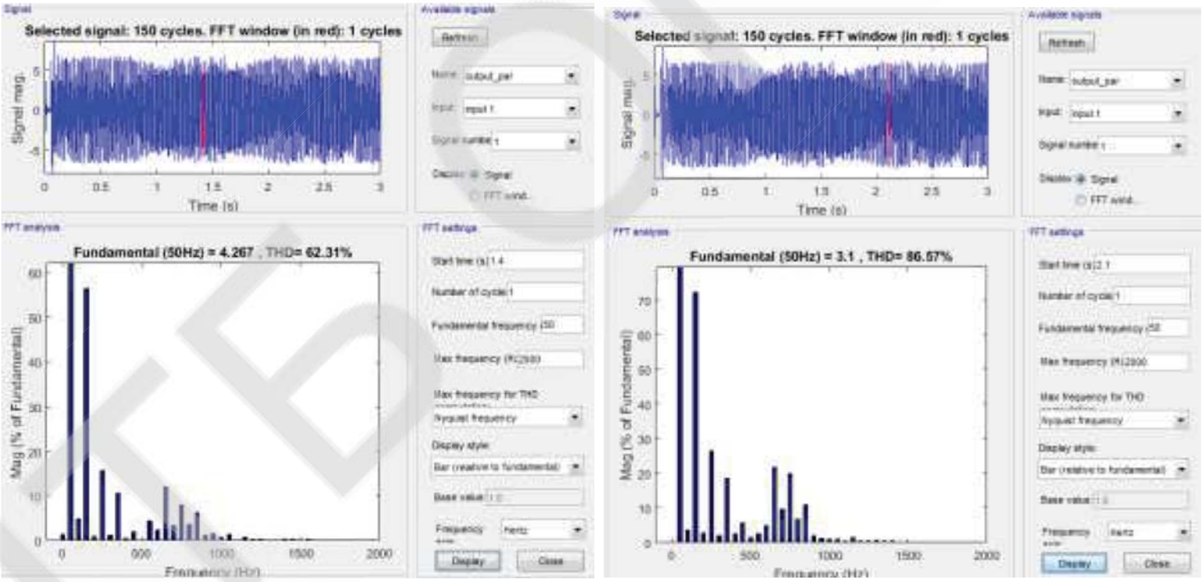


Figure 3.7 – The results of the quality of the output current of the network without the use of the algorithm

The results and comparison of the assessment of the current quality of the network with/without the use of the incremental conductivity algorithm are presented in table 3.6.

Table 3.6 – Results of current quality assessment with \ without using the incremental conductivity algorithm

№	Evaluation time, s	THD with MPPT, %	THD without MPPT, %
1	0,2	83,45	82,25
2	0,4	82,16	80,92
3	0,6	81,80	76,21
4	1	62,67	79,65
5	1,4	66,01	60,82
6	1,7	62,91	74,29
7	2,1	83,98	89,85
8	2,5	73,26	60,54
9	2,9	77,87	78,50

Therefore, increasing the power degrades the current quality, and therefore it is necessary to use power factor correctors or active power current filters in the system.

IV. CONCLUSIONS

The scientific novelty of the study is revealed in the method of comprehensive evaluation of the efficiency of the power supply system based on photovoltaic converters. It includes monitoring and ensuring the selection of maximum power from the array of solar panels using a modified incremental conductivity algorithm and simultaneous monitoring of the quality of currents in the system by the criterion of harmonic distortion.

The task of tracking the point of maximum power in the power system is to constantly adjust the system so that it provides maximum power from photovoltaic converters.

There are no oscillations around the point of maximum power in stationary conditions in the method of incremental conductivity, but it is not stable during transients, there are some ripples.

The maximum power of the system is achieved by the algorithm. Power is equal to 100.3 kW (maximum power point 100.7 kW) under the action of the MRRT algorithm at an illumination of 1000 W/m². Whereas when the algorithm is turned off, the power in this light is 85.08 kW. The power under the algorithm increased by 17.6%.

V. REFERENCES

1. Vella, H. (2020, December 4). Solar Energy Optics: expanding efficiency. Power Technology. https://www.power-technology.com/features/solar-energy-optics-expanding-efficiency/

2. Grigorash, O.V., Tropin V.V., Oskina A.S. (2012). On the efficiency and feasibility of using renewable energy sources. *Polythematic network electronic scientific journal of the Kuban State Agrarian University*, 9(083). https://ur.booksc.org/book/36458478/b1cbae

3. Ivanchura, V.I., Chubar, A.V., Fast, S.S. (2012). Energy models of elements of autonomous power supply systems. *Journal of Siberian Federal University. Technics and techology*, 2, 179-190. http://elib.sfu-kras.ru/handle/2311/3049

4. Mathworks. Solar Cell. https://www.mathworks.com/help/physmod/elec/ref/solarcell.html

5. Mathworks. MPPT-algorithm. https://www.mathworks.com/solutions/power-electronics-control/mppt-algorithm.html?s_tid=srchtitle

6. Hohm, D. P.; Ropp, M. E. “Comparative Study of Maximum Power Point Tracking Algorithms.” Progress in Photovoltaics: Research and Applications, vol. 11, pp. 47–62, June 2002.

7. H. Malek and Y. Chen, “BICO MPPT: a faster maximum power point tracker and its application for photovoltaic panels,” *International Journal of Photoenergy*, vol. 2014, Article ID 586503, 9 pages, 2014.

8. Duy C. Huynh, «An Improved Incremental Conductance Maximum Power Point Tracking Algorithm for Solar Photovoltaic Panels», Publication, 2011.

9. Srushti R. Chafle, Uttam B. Vaidya, «Incremental Conductance MPPT Technique FOR PV System», *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* Vol. 2, Issue 6, June 2013.

10. Shweta Pandey, Prasanta Kumar Jena «A Review on Maximum Power Point Tracking Techniques for Photovoltaic Systems», *International Research Journal of Engineering and Technology (IRJET)*, June 2017.

11. Ratna Ika Putria, Sapto Wibowob, Muhamad Rifa’i, «Maximum power point tracking for photovoltaic using incremental conductance method», 2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014.

12. Reva K. «Standarts for PV modules and components», International Scientific-Practical Conference students and young scientists "Youth science – 2017: socio-economic and humanitarian aspects of society development", Chernihiv National University of Technology, April 26-27, 2017, p. 439 - 440.

13. Reva, K., Stepenko S. (2017). Research of characteristics of elements of autonomous power supply systems on the basis of photoelectric converters. *Technical sciences and technologies: scientific journal*, 2(8), 162-171. http://www.irbis-nbuv.gov.ua/cgi-bin/irbis_nbuv/cgiirbis_64.exe?I21DBN=LINK&P21DBN=UJRN&Z21ID=&S21REF=10&S21CNR=20&S21STN=1&S21FMT=ASP_meta&C21COM=S&2_S21P03=FILA=&2_S21STR=tnt_2017_2_21

14. Stepenko, S.A, Bashinsky, K.V. (2016). Assessment of the possibility of using alternative energy sources based on photovoltaic converters in the Armed Forces of Ukraine. *Weapons Systems and Military Equipment*, 4(48), 50-56. http://www.hups.mil.gov.ua/periodic-app/article/17325