INVESTIGATION OF THE EFFICIENCY OF POWERING AN OZONATOR PLANT FROM PHOTOVOLTAIC INSTALLATIONS

Abdikadyrov Askar Aitmyrzaevich[1], Kalandarov Palvan Iskandarovich[2]
[1]Candidate of Technical Sciences, Associate Professor
[1]Institute of Automation and Information Technology, Satpayev University, Almaty Kazakhstan;
[2]Academician of the International Academy of Agrarian Education,
Doctor of Technical Sciences, Professor
[2]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers"
National Research University
https://doi.org/10.5281/zenodo.10803913

Abstract. *The article deals with the issues of power supply of the ETRO - 03 ozonator installation, operating on the basis of an electric corona discharge, using a small solar power plant, where the modular type of solar panel design allows powering the ozonator unit, the disadvantage of solar panels is their high cost and low economic efficiency. The voltage of the solar cells is converted to alternating voltage through an inverter and transmitted through a filter to the ozonator, to improve the quality of electricity, the filter is switched on after the inverter, designed for lower frequencies. The main factor in a solar power plant are solar cells, as well as composite elements, including an inverter that converts a constant voltage into an alternating output voltage, a wiring diagram of solar panels is presented, which demonstrates the multilevel voltage of the inverter (8V, 13V and 26V) and a graph of their sinusoidal voltage, mathematical modeling is performed at voltage levels of 8V, 13v and 26v with pulse-amplitude control in MATLAB 7.0 environment.*
Keywords: *solar battery; inverter; ozonator; electric corona discharge; multichannel inverter; alternating voltage.*

1. Introduction

The most important characteristic of photovoltaic systems is the amount of electricity generated in a given period (day, month, year), there are a number of studies that determine this in natural conditions. Among them, it is worth noting the detailed works of A.V. Yurchenko, V. Durish, and O. Struss [1,2]. The studies present the results of measurements of various photovoltaic parameters for several types of silicon wafers, and determine the influence of various factors, in particular, temperature when using a solar concentrator [3].

In 2009, Spectrolab (a subsidiary of Boeing) demonstrated a solar array with an efficiency of 41.6% [4], while in January 2011 the company's solar panels entered the market with an efficiency of 39% [5]. In 2011, California Solar Junction achieved a higher efficiency of 43.5% for a 5.5×5.5 mm photovoltaic cell, a 1.2% increase over previous years [6].

In 2012, Morgan Solar developed the Sun Simba system made of polymethyl methacrylate (plexiglass), germanium and gallium arsenide, combining a hub with a panel on which a photovoltaic cell is installed, but the efficiency of the system in a stationary position of the panel was 26 - 30% (depending on the season and the angle at which the sun is located), which is an order of magnitude higher than the practical efficiency of solar cells based on crystalline silicon [7].

Analyzing the problems of power supply of an ozonator plant through a small solar power plant and increasing the economic efficiency of the ozonator, it is necessary to improve the connection schemes of solar panels. However, Swetapadma P. believes that the problem of evaluating the performance of a solar energy conversion system using a multi-level H-bridge cascade converter [8], as well as the control of power flow and voltage through solar and wind power plant inverters in a multi-grid system, is a more pressing issue [9]. A multi-level inverter, which regulates the power output using a photovoltaic system, forms the basis of the system [10]. In this regard, a complex scientific and technical task, the problem of studying methods for the efficiency of feeding an ozonator plant from a small solar power plant seems relevant and timely. In this regard, there is a need to conduct a study aimed at the analysis and evaluation of multilevel inverters 8V, 13V, 26V and their sinusoidal voltages, as well as the development of a mathematical model, on the basis of which the conditions for achieving the highest efficiency of the proposed devices using Matlab and Mathcad programs are determined.

2. Materials and methods

Photovoltaic (PV) inverter technology is undergoing significant changes, looking at some of the fastest growing trends in photovoltaic inverters, as well as the potential of financial compensation mechanisms for photovoltaic inverters providing supporting functions. Limiting the intermittent power of wind and photovoltaic installations is necessary in order to avoid unacceptable voltage and frequency fluctuations in the interconnection [11].

In this study, the conversion ratios of three different photovoltaic inverters for different active and reactive power installation points were measured. Based on these measurements, two mathematical models have been proposed to express the cost of conversion as a function of active and reactive power. The first model is empirical and extends the existing model by adding a term to account for reactive power; The second model takes into account the general loss mechanisms at the converter conversion stage and the effect of reactive power on it; Comparison of the two models considered in the basic version.

In the work, the presented models work with high accuracy over the entire operating range and require only a small number of known efficiency values for parameterization. These new models have several applications: For PV park operators, they can accurately estimate the individual costs of photovoltaic plants supplying reactive power to the grid. For power system operators, the relative costs of different reactive power sources can be analysed [14, 15].

For the efficient integration of photovoltaic equipment into the electrical grid, a method of controlling the operation of an inverter is proposed. According to this method, the demand for electricity from the grid is monitored, and the angle and voltage of the inverter are regulated by control signals, this method improves the quality of electricity and the stability of the interconnected system [20].

Likewise, there are noteworthy studies that consider the simultaneous implementation of fast frequency control and power fluctuation reduction by photovoltaic systems [16]. At the same time, the direction of modeling and analysis of magnetically coupled converters with a resistance source for photovoltaic systems deserves attention [17]. Simon A. (et al.) proposed a hierarchical control system to facilitate variability and service delivery in photovoltaic (PV) plants. Subsequently, it was shown that the proposed control algorithm is 10 times more effective when grouped using alternative control methods described in the literature [18]. The methods used in the studies under consideration for the power efficiency of a small solar power plant of an ozonator plant using the ETRO-03 corona discharge, and the problem of the study is that in some cases the pumps and compressors of ozonator plants fail due to the lack of ideal sinusoidal voltage.

3. Results and Discussions

Converting solar energy to alternating current is a well-known method (Figure 1) in which solar cells are connected in series and in parallel. The voltage of solar cells is converted to alternating voltage through an inverter (I) and transmitted to the load through a filter (F) [27].

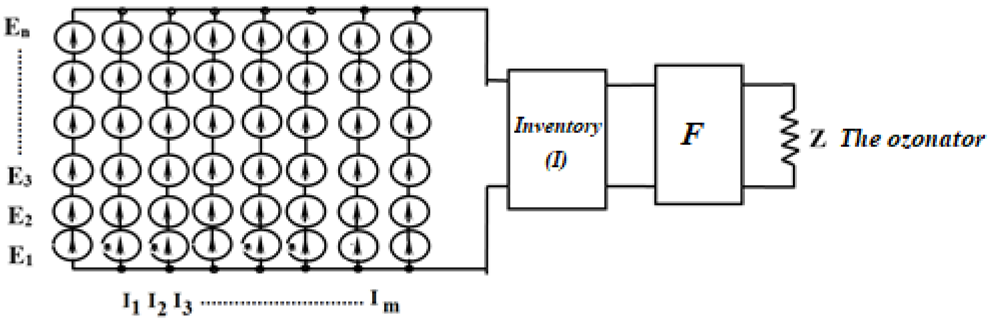


Figure 1. Known Solar Panel Connection Diagram

In this case, the inverter must have a sufficiently high energy performance (specified power, efficiency, power factor, etc.) and the quality of the generated electricity (sinusoidal voltage curve, frequency and voltage stability).

The modular type of solar panel design allows you to power any heavy-duty installations and provides them with very efficient energy. The disadvantage of solar panels is that, economically, the cost is very high and hence their efficiency is low. Each solar cell module is rated for a specific DC voltage and current. By means of series and parallel connection of these modules, it is possible to obtain electrical energy of any power, voltage and current.

In order to obtain high-quality electricity after the inverter, it is necessary to connect filters designed for low frequencies. When the power of solar panels is increased to tens or hundreds of kilowatts, the overall size of the filter increases, resulting in a loss of power on the filter and a decrease in the efficiency of the entire system. Harmonic analysis of the voltage curve shows that higher harmonics make up a larger proportion of voltage harmonics than fundamental harmonics. Higher voltage harmonics are the electrical energy generated by solar panels that is either lost or captured by the filter before it reaches the consumer. This part of the energy of solar panels, which is insufficient for the consumer, increases power losses [29] (Fig. 1).

If n solar panels are connected in series and m in parallel, the capacity of a solar power plant can be calculated using the following formula

$$P_{SE} = n \cdot m \cdot P_m, \qquad (1)$$

Where P_m is the power of one solar module (battery)?

As a result, some of the solar energy is lost in the conversion system, and not all connected expensive solar panels are used to their full potential. On the one hand, it increases the cost of solar converters, on the other hand, it requires an optimized, energy-efficient system for converting solar energy into power frequency and voltage electricity, in which case the technical and economic indicators of the system appear to be high, when the cost and economic costs of the materials necessary for the conversion should be minimal [30].

In multi-level inverters, the generation of a voltage approaching a sine wave is carried out by adding up the voltages of the solar cell sources. Figure 2 shows the wiring diagram of a solar cell and the generation of a multi-level voltage from the voltage of the solar cells.

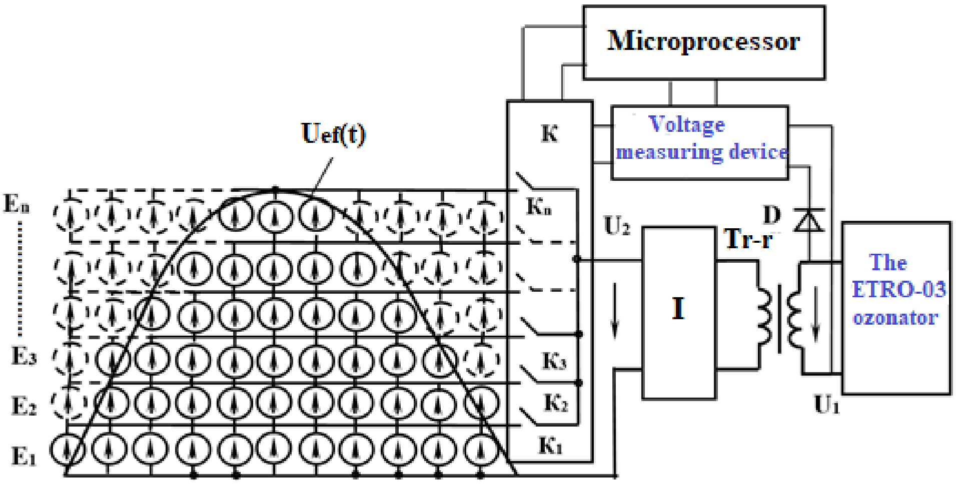


Figure 2. Proposed Solar Energy Conversion Scheme

Where is: $E_n$and I_m - EMF and current of the multi-level solar module, I - inverter, Tr-p - transformer, - transistor switches, D - diode, - mains voltage. $K_n U_{ef}(t)$

The formation of a multi-level voltage at the inverter input is carried out by dividing the solar panels connected in series into *N* voltage levels with different values and different switching times. In this case, each voltage level has different values for the current connected in parallel between the solar panels. Each voltage stage is fed to the inverter via transistor switches. The inverter is assembled on four IGBT transistors in a bridge circuit. The inverter's job is to convert the multi-level DC voltage of the series-connected solar panels into alternating voltage. In this way, a multi-level voltage is generated in the load, which is close to a sinusoidal shape.

A multi-level inverter works in the power grid as follows. The multi-level voltage supplied to the input of the inverter is compared with the mains voltage by a measuring device. If the corresponding level of multi-level voltage is equal to the voltage level of the power line, a command is sent to the microprocessor to turn on the corresponding transistor switch. It should be noted that the solar-to-alternating current conversion circuit uses special transformers available. K_n

Figure 3 below shows a graph of the sine wave voltage of the power grid recorded for the multi-level voltage of the inverter. According to the intersection points of these graphs, a transistor switch is connected. Calculations show that the tension of the line of force must be fixed in a multi-level stress, then the equality of these stresses is observed [31]. K_n

Solar cells are known to have a staggered arrangement, but they are not used in the same amount. The solar panels in Figure 2 are shown by the dotted line. To do this, you need to calculate the number of unused solar panels in a solar power plant. If each solar module (batteries) in a known conversion scheme (Figure 1) is considered as an element of a certain matrix, then all active and passive solar modules (SM) can be calculated. Let's denote the total number of active solar modules connected in series and in parallel, as can then be represented in the form of a matrix as:$A_{общ}.A_{общ}.$

$$\mathrm{A}_{Gen.} = \begin{bmatrix} a_{\mathrm{n}1} & a_{\mathrm{n}2} & \cdots & a_{\mathrm{nm}} \\ \vdots & \vdots & \vdots & \vdots \\ a_{11} & a_{12} & \dots & a_{1\mathrm{m}} \end{bmatrix} \qquad (2)$$

Where is: $\mathrm{A}_{Gen.}$is the CM matrix, $n \cdot mN$ - the number of solar panels connected in series, and *m* - Number of solar panels connected in parallel.

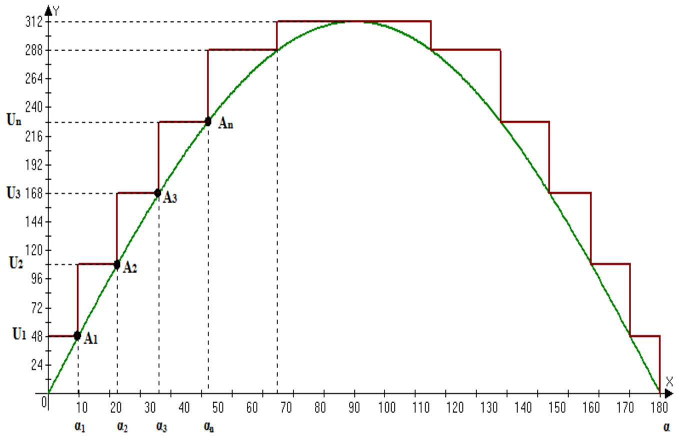


Figure 3. Diagram of the sine wave voltage of the power grid made on a multi-level voltage converter

If we select solar modules from a common matrix that are involved in the formation of a multi-level voltage close to a sine wave (see Figure 2) and label them as an active matrix, this matrix will look like this:

$$A_{\mathrm{akt.}} = \begin{matrix} a_{i1} & a_{i1} & \cdots & a_{ij} \\ \vdots & \vdots & \vdots & \vdots \\ a_{11} & a_{12} & \cdots & a_{1j} \end{matrix} \qquad (3)$$

where: is the CM matrix, $A_{\mathrm{акт.}} i \cdot ji$ is the CM connected in series, j is the CM connected in parallel. A matrix of passive solar modules that do not participate in the formation of multi-level stress (shown in Figure 2 by a dotted line), then this matrix will be equal to:

$$A_{pas.} = A_{gen.} - A_{\mathrm{akt.}} \qquad (4)$$

Thus, there is a part of passive solar modules that are not involved in the solar energy conversion scheme. Taking into account the percentage of active and passive elements, it is possible to calculate the efficiency of the developed conversion scheme and the savings on CM, that is:

$$\mathrm{E}_{eff.}CM = \left(\frac{A_{gen.} - A_{akt.}}{A_{gen.}}\right) \times 100\% \qquad (5)$$

The voltage values of each level can be the same or different, in which case the switching time of each level is different. In view of the above, the method of calculating the switching angle (time) for each voltage level is determined based on the fact that the generation of multi-level voltage at the output of the inverter is close to a sine wave.

For a more detailed analysis, simulations were performed at 8, 13, and 26 voltage levels with pulse-amplitude control in the MATLAB 7.0 environment. Constant voltage sources were used as solar panels. The results of the simulation confirmed the principle of generating a multi-level voltage close to a sine wave with amplitude-pulse control at the output of the transducer. Table 1 shows solar panel savings and voltage distortion (THD) as a function of the number of voltage levels. As you can see from the calculations, saving on expensive solar panels is very important because the cost of solar panels accounts for most of the cost of a solar energy conversion system.

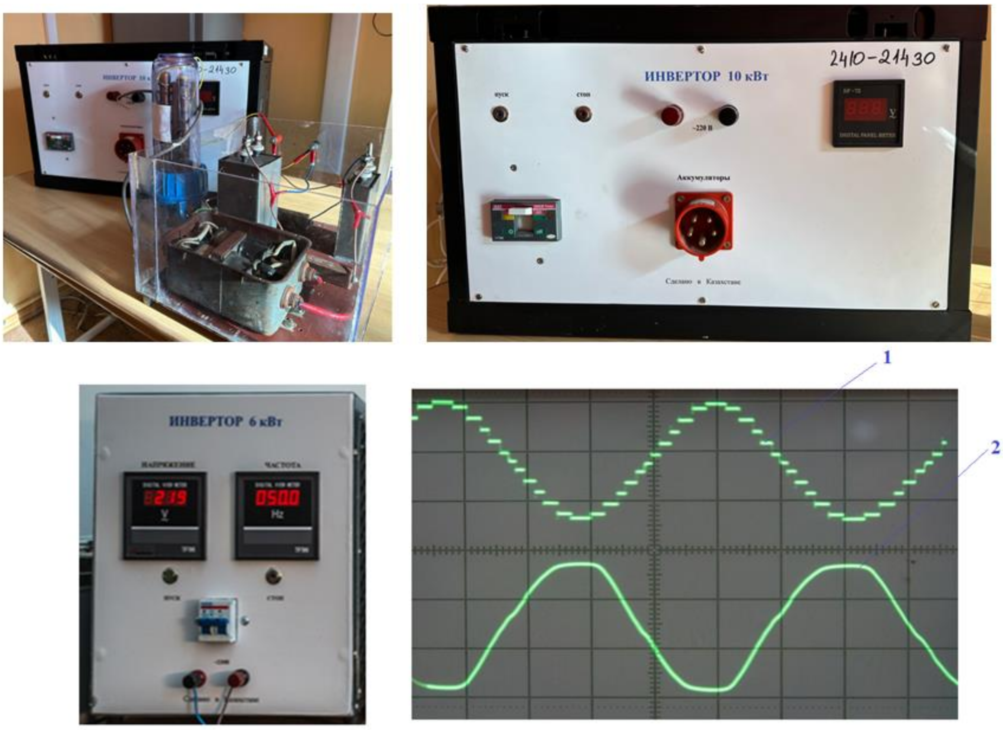
Table - 1

Solar Cell Savings and Voltage Distortion (THD)

N-Number of Voltage Levels	Saving Solar Panels	Voltage Distortion Factor (THD)
8 - number of voltage levels		
13 - number of voltage levels		
26 - number of voltage levels		

As you can see from the voltage graph and the table above, the higher the number of voltage levels, the closer the multi-level voltage at the output of the inverter to the sine wave. This means that the voltage distortion factor (THD) is negligible. In power systems, voltage distortions of up to THD <5% are allowed. However, this increases the number of switching operations, increases the cost of switches, and complicates the control circuitry.

Theoretical calculations show that power filters of industrial frequency 50 Hz with a power of 6-10 kW have a large weight and volume. As a result of experimental research, an inverter with a capacity of 6-10 kW with eight rectifiers was developed and manufactured. The inverter is powered by a rechargeable battery (Fig. 4). The figure shows the waveform of the inverter, as well as the output parameters of the inverter and the output voltage. As you can see from the waveforms, the output voltage of an 8-level inverter is close to a sine wave.



Where 1 is the output voltage of the inverter, 2 is the voltage of the node

Figure 4. General view of 6-10 kW inverter

It is known from studies that the key equipment of modern photovoltaic plants that ensures the operation of the ETRO-03 ozone generator, that is, the uninterrupted supply of electricity to autonomous consumers, is an inverter. It is the inverter that converts the direct current generated by photovoltaic solar modules or batteries into alternating sine current (AC) at the output. Modern 6-10kW inverters automatically monitor the maximum power point in real time according to the volt-current characteristics of the photovoltaic solar modules, and the system is controlled by the controller. The system controller solves the problem of converting the input voltage and current, which can vary greatly depending on weather conditions and the illumination of the solar panels.

Calculation of the uptime of the uninterruptible power supply (UPS).

Given the required battery capacity, the UPS runtime for the required UPS/inverter redundancy time under a given load (ETRO-03) can be roughly calculated using the following formula.

$$\mathrm{C} = \frac{t(hour)\cdot P(W)}{U(\mathrm{B})}, (\mathrm{A}\cdot hour) \quad (6)$$

It is known that the capacity of the battery only increases when it is connected in parallel. In a series connection, the voltage of the batteries is added together and the capacity remains equal to the nominal value of a single power supply.

$$t(hour) = \frac{\mathrm{C}(\mathrm{A}\cdot hour)\cdot U(\mathrm{B})}{P(W)} \quad (7)$$

Where t is the reserve time (hours); C is the total capacity of the battery (Ah), U is the total voltage of the battery (V); P is the total load power (W).

The power of the load connected to the UPS is 3000 (W), the time is 8 (h), and the battery voltage is 12 (V). Calculating UPS Runtime Using the Required Battery Capacity:

$$\mathrm{C} = \frac{t(hour)\cdot P(W)}{U(\mathrm{B})} = \frac{8\cdot 3000}{12} = 2000(\mathrm{A}\cdot \text{час}) \quad (8)$$

The power of the load connected to the UPS is 3000 (W), the battery capacity is 2000 (Ah), the battery voltage is 12 (V):

$$t = \frac{C(A\cdot hour)\cdot U(\mathrm{B})}{P(\mathrm{Вт})} = \frac{2000\cdot 12}{3000} = 8\ (hour) \quad (9)$$

A more accurate formula for calculating the UPS standby time takes into account the efficiency and depth of discharge of the battery. η - inverter efficiency (nameplate value), efficiency value for UPS and Sib Kontakt inverters is from 0.9; P is the load power (W); U is the battery voltage (V); K p is the depth of discharge of the battery, 0.6 - 0.8 (that is, the depth of discharge of the battery is from 60% to 80%), the usual value is 0.75.

$$\mathrm{C} = \left(\frac{t(hour)\cdot\left(\frac{P(W)}{\eta}\right)}{U(V)}\right)\cdot\left(\frac{1}{K_{\text{п}}}\right) = \left(\frac{8(\text{час})\cdot\left(\frac{3000(W)}{0.9}\right)}{12(V)}\right)\cdot\left(\frac{1}{0.75}\right) \approx 2962.222(\mathrm{A}\cdot hour) \quad (10)$$

$$t = \left(\frac{C(A\cdot hour)\cdot U(B)}{\frac{P(W)}{\eta}}\right)\cdot(\mathrm{K}_{\text{п}}) = \left(\frac{2962.222(A\cdot hour)\cdot 12(B)}{\frac{3000(W)}{0.9}}\right)\cdot(0.75) \approx 8\ (hour) \quad (11)$$

Calculation of the required active power of the UPS /inverter

If the power of the UPS is less than the total load, the unit will shut down immediately after start-up. Before purchasing an uninterruptible power supply, calculate the power consumption of all the equipment that will be powered by it. For reactive loads (e.g., electric motors, air conditioners, microwave ovens), the total power is usually given in volt-amperes (VA). If active power is generated, when calculating the required UPS power, it is necessary to take into account the reactive component:

$$P_a\,(W) = \frac{S(\mathrm{B}\cdot\mathrm{A})}{\cos(\varphi)} \quad (12)$$

Here: - active power in watts; S (B·A) is the apparent power in volt-amperes; cos(φ) is the power factor, usually 0.75 for an inductive load. Also keep in mind that in the technology with electric motors, the inrush currents are three to eight times higher than in the operating mode. $P_a\,(W)$

For such devices, a sinusoidal current is required, and the inverter shown in Fig. 4, produces just such an alternating voltage. Automatic calculation of the maximum power point from solar panels made it possible to increase the efficiency of solar energy use by 20-30% and to build a circuit with several panels connected in series when feeding an ozonator based on the ETRO-03 electric corona discharge. The battery voltage was significantly higher to reduce DC losses in the conductors. A graph to determine the point of maximum power is shown below (Fig. 5).

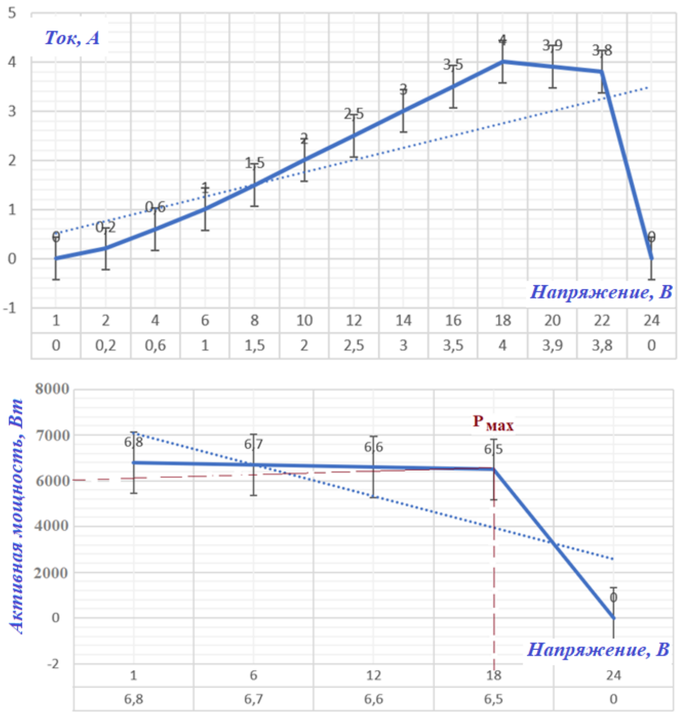


Figure 5. Maximum Power Point Determination Graph
(Study Results)

Depending on the technical requirements and operating conditions of the solar power plant, it is necessary to solve the problem of choosing an inverter. At the stage of designing an electrical circuit, it is necessary to take into account the availability of different types of inverters with different modes of operation and technical characteristics, for example, a comparison of the production and technical capabilities of currently produced inverters is given in Table 2 [32-34].

Table -2

Comparative Results of the Volume and Technical Capabilities of the Inverter Network

Functional	Off-grid Inverter	On-Grid Inverter	On-grid and off-grid inverter
Connecting the Batteries	+	-	+
Diesel Power Plant Connection	+	-	+
Ability to increase power	+	+	+
Power supply to the load when the main line is disconnected	+	-	+
Battery-free operation	-	+	+

When planning power supply to consumers in areas where there are no power lines, it is recommended to use autonomous converters. Such converters provide consumers with electricity generated by solar panels during the day and energy stored in batteries at night. The use of stand-alone inverters allows the system to operate independently of the external power grid (the diagram is shown in Figure 6).

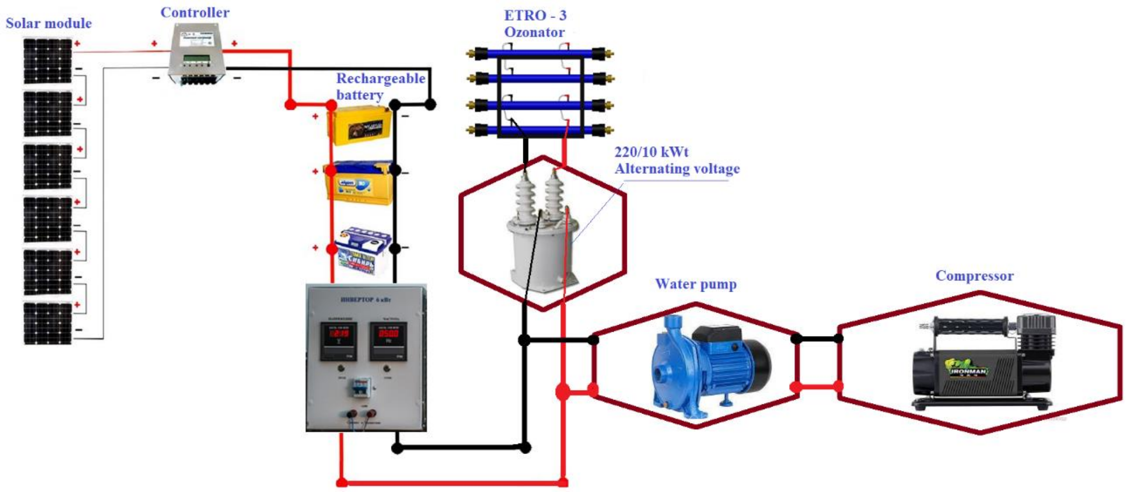


Figure 6. Ozonator Power Supply Circuit Based on Electric Corona Discharge with Solar System

(Wiring diagram of a stand-alone converter)

Thus, the use of multi-level inverters as a power grid for solar power plants allows you to save up to 30.5% on solar panels and get a completely sinusoidal voltage at the output.

Findings

Summing up the results of the study, it can be noted that the study of the efficiency of energy supply from a small photovoltaic plant to an ozone plant gave unequivocal results. The research was aimed at studying the main role of 6 kW inverters in the phase with the external power grid, as well as the synchronization of voltage and generation frequency, which means that the solar panel inverter has a protective function that allows it to be quickly disconnected from the grid in the event of an external power line failure or other serious errors. Options for connecting various types of inverters that allow you to choose schemes of solar power plants are also considered. The presence or absence of external power lines in the area of the planned photovoltaic plant is taken into account as initial data for the selection of equipment and its type.

After assessing the local conditions and technical requirements for the solar power plant, the equipment configuration, capacity and operating mode are determined. The use of state-of-the-art inverters ensures the durability and reliability of the entire system. The high efficiency of the presented technical solutions is confirmed by the experience of designing and operating modern solar power plants.

REFERENCES

1. Yurchenko A.V. Results of field tests of silicon solar battery in climatic conditions of Tomsk // Proceedings of the International Academy of Higher School Sciences. – 2004.– № 2 (28). – Pp. 145-150. https://cyberleninka.ru/article/n/issledovanie-effektivnosti-raboty-solnechnoy-batarei-v-polevyh-usloviyah/viewer
2. Durisch W., Struss O., Kai R. Efficiency of selected photovoltaic modules under varying climatic conditions // Renewable energy – the energy for the 21st century: Proc. of VI World renewable energy congress. – Brighton, Great Britain, 2000. Pp. 779–788. https://pdfs.semanticscholar.org/53e4/3ee1715596b8fffda4a211dbe5e4adbadd80.pdf

3. Bakirov M.Ya. Photovoltaic and radiation characteristics of silicon solar cells at elevated illuminances and temperatures // Physics and technology of semi-conductors. 1997. № 5 (31). Pp. 520-522. https://journals.ioffe.ru/articles/viewPDF/32807
4. Australians have set a new record for the efficiency of solar panels. Membrana. Membrana (August 28, 2009). Accessed: March 6, 2011. Archived from the original on June 25, 2012. https://www.nanonewsnet.ru/blog/empirv/avstraliitsy-ustanovili-novyi-rekord-kpd-solnechnykh-batarei
5. Solar panels with record efficiency are entering the market. Membrana. Membrana (November 25, 2010). Accessed: March 6, 2011. https://ru.wikipedia.org/wiki/%D0%A1%D0%BE%D0%BB%D0%BD%D0%B5%D1%87%D0%BD%D0%B0%D1%8F_%D0%B1%D0%B0%D1%82%D0%B0%D1%80%D0%B5%D1%8F
6. Solar Junction Breaks Concentrated Solar World Record with 43,5 % Efficiency https://www.businesswire.com/news/home/20110414005387/en/Solar-Junction-Breaks-World-Record-with-43.5-Efficient-CPV-Production-Cell
7. How to concentrate sunlight without concentrators. https://energobelarus.by/news/V_mire/kak_skontsentrirovat_solnechnyy_svet_bez_kontsentratorov/
8. Swetapadma Panigrahi; Amarnath Thakur; Devashish; Madhu Singh. Performance Evaluation of Solar Energy Conversion System Having Seven-level Cascaded H-bridge Inverter. 2019 IEEE International Conference on Innovations in Communication, Computing and Instrumentation (ICCI). **https://doi.org/** 10.1109/ICCI46240.2019.9404440
9. Harshit Vallecha; Shivam. Power flow management and voltage control using solar and wind farm inverters in multi-line system. 2015 Annual IEEE India Conference (INDICON). **https://doi.org/** 10.1109/INDICON.2015.7443511.
10. Arvind Mittal; Kavali Janardhan; Amit Ojha. Multilevel inverter-based Grid Connected Solar Photovoltaic System with Power Flow Control. 2021 International Conference on Sustainable Energy and Future Electric Transportation (SEFET). **HTTPS://DOI.ORG/** 10.1109/SeFet48154.2021.9375753
11. Rajiv K. Varma. EMERGING TRENDS WITH SMART SOLAR PV INVERTERS. Smart Solar PV Inverters with Advanced Grid Support Functionalities. **Copyright Year:** 2022. **Page(s):** 431 – 464. ISBN Information: 9781119214212. Wiley-IEEE Press. **https://doi.org/** 10.1002/9781119214236.ch9
12. S.S. Shema; I. Daut; M. Irwanto; C. Shatri; N. Syafawati; N. Ashbahani. Study of inverter design and topologies for photovoltaic system. International Conference on Electrical, Control and Computer Engineering 2011 (InECCE). **HTTPS://DOI.ORG/** 10.1109/INECCE.2011.5953934
13. Huanqi Tao; Gujing Han; Min Zou. The System Analysis of Solar Inverter Based on Network Controlling. 2010 International Conference on Challenges in Environmental Science and Computer Engineering. **https://doi.org/** 10.1109/CESCE.2010.258
14. Robin Grab; Franziska Hans; Mariano Ivan Rojas Flores; Heribert Schmidt; Soenke Rogalla; Bernd Engel. Modeling of Photovoltaic Inverter Losses for Reactive Power Provision. **Published in:** IEEE Access (Volume: 10). **Date of Publication:** 10 October 2022. **https://doi.org/** 10.1109/ACCESS.2022.3213272

15. Alpesh Desai; Vatsal Shah; Indrajit Mukhopadhyay; Abhijit Ray. Multiple MPPT based String Inverter effect on Annual performance: Observations at Utility scale Solar PV Plants. 2021 IEEE 48th Photovoltaic Specialists Conference (PVSC). **https://doi.org/** 10.1109/PVSC43889.2021.9518823.
16. Rajiv K. Varma; Mohammad Akbari. Simultaneous Fast Frequency Control and Power Oscillation Damping by Utilizing PV Solar System as PV-STATCOM. IEEE Transactions on Sustainable Energy (Volume: 11, Issue: 1, January 2020). **https://doi.org/** 10.1109/TSTE.2019.2892943
17. Chandrashekhar Badachi; Pooja S Laad. Modelling and Analysis of Magnetically Coupled Impedance Source Inverter for Solar Photovoltaic Systems. 2021 6th International Conference on Inventive Computation Technologies (ICICT). **https://doi.org/** 10.1109/ICICT50816.2021.9358477
18. Simon A. Julien; Amirhossein Sajadi; Bri-Mathias Hodge. Hierarchical Control of Utility-Scale Solar PV Plants for Mitigation of Generation Variability and Ancillary Service Provision. IEEE Transactions on Sustainable Energy (Volume: 13, Issue: 3, July 2022). **https://doi.org/** 10.1109/TSTE.2022.3149451
19. W.T. Jewell. Electric utility experience with solar photovoltaic generation. IEEE Transactions on Energy Conversion (Volume: 4, Issue: 2, June 1989). **https://doi.org/** 10.1109/60.17907
20. A. Karlis; P. Dokopoulos. Small power systems fed by hydro, photovoltaic, wind turbines and diesel generators. Proceedings of Third International Conference on Electronics, Circuits, and Systems. **https://doi.org/** 10.1109/ICECS.1996.584558.
21. B. Venkatasamy; L. Kalaivani; P.R. Prakash; S. Prabhu; B. Mathana Gopal. Performance Analysis of Grid- Tie Inverter for Reactive Power Injection Mode in Hybrid Wind Solar Energy System. 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI). **https://doi.org/** 10.1109/ICOEI.2018.8553869
22. Moushumi Patowary; Gayadhar Panda; Bimal C Deka. Relative Influence of Intelligent Current Controllers on Power Quality in Grid-Interactive Solar Inverter System. 2018 2nd International Conference on Power, Energy and Environment: Towards Smart Technology (ICEPE). **https://doi.org/** 10.1109/EPETSG.2018.8658930.
23. Mohamed Ibrahim A. Arafa; El-Sayed Soliman A. Said; Mahmoud Elwany. An optimized design criteria of non-outage and power reduction for hybrid solar-grid system (residential homes — case study). 2017 Nineteenth International Middle East Power Systems Conference (MEPCON). **https://doi.org/** 10.1109/MEPCON.2017.8301163.
24. K Biju; Rijil Ramchand. Modeling and simulation of a novel solar PV/ battery hybrid energy system with a single phase five level inverter. 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES). **https://doi.org/** 10.1109/SPICES.2015.7091479
25. Kah Yung Yap; Chee Ming Beh; Charles R. Sarimuthu. Fuzzy logic controller-based synchronverter in grid-connected solar power system with adaptive damping factor. Chinese Journal of Electrical Engineering (Volume: 7, Issue: 2, June 2021). **https://doi.org/** 10.23919/CJEE.2021.000014
26. Gefei Kou; Kevin Phelps; Jonathan Deverick; Roland Brandis; Mark McVey; Ariel Valdez; Richard LaVigne; Aaron Reynolds. Load Rejection Overvoltage of Utility-Scale

Distributed Solar Generation. IEEE Transactions on Power Delivery (Volume: 35, Issue: 4, August 2020). **https://doi.org/** 10.1109/TPWRD.2019.2951949.

27. Taissariyeva K.N., Issembergenov N. The research of the “Solar panels – commutator – inverter – load” system with the pulse-amplitude control. PROCEEDINGS OF SPIE Photonics Applications in Astronomy, Communications, Industry, and High-Energy Physics Experiments 2014 Volume 9290
28. J. Basic. «Reduction of Harmonic in Multilevel Inverters using FA and LAFA ALGORITHMS». Journal of Basic and Applied Scientific Research. Appl. Sci. Res., 3(1s)130-135, 2013. ISSN 2090-4304.
29. N.T. Isembergenov, B.T. Matkarimov, Using Genetic Algorithm for Finding Switching Angles of a Single-phase Multilevel DC/AC Converter on Solar Modules. Proceedings of the Eighth International Conference on Machine Learning and Applications, 13-15 November. 2009, New York.
30. Mohammad Farhadi Kangarlu, Student Member, IEEE, and Ebrahim Babaei, Member, IEEE. A Generalized Cascaded Multilevel Inverter Using Series Connection of Submultilevel Inverters. IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 28, NO. 2, FEBRUARY 2013. Res., 3(1s)625- 635.
31. Issembergenov N., Taissariyeva K.N. The multilevel on IGBT transistors for transformation of solar energy to the electric power. BULLETIN OF NATIONAL ACADEMYOF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN. Volume 2, Number 354 (2015), pp. 183-186.
32. Chubais A. B., Zubakin V. A., Kopylov A. E. RES development in Russia: Technologies and Economics. Tochka Publishing House, Moscow 2020 https://www.labirint.ru/books/767676/
33. Kalandarov P.I., Korenkov M.S., Rozhnov A.P. INNOVATION IN THE ELECTRIC POWER INDUSTRY AND IN MINING TECHNOLOGY AT THE ANGREN Mine OF THE Future SECTION. 2010. No. 2. pp. 63-67.
34. Kalandarov P.I., Sytdykov R.A. ENERGY DEMAND MANAGEMENT AND MODES OF POWER SUPPLY SYSTEMS//Mathematical and software systems in the industrial and social spheres. 2011. No. 1-2. pp. 20-25.