IOP Conference Series: Materials Science and Engineering

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To cite this article: I Sapaev *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **883** 012116

IOP Conf. Series: Materials Science and Engineering **883** (2020) 012116 doi:10.1088/1757-899X/883/1/012116

Matlab-model of a solar photovoltaic station integrated with a local electrical network

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Abstract. This article considers a model of a solar photovoltaic station (PVS) integrated with a local electrical network on the example of a 20 kW PVS installed in the building of the Tashkent State Technical University named after Islom Karimov. The Basic SIMULINK model of an equivalent PVS was used for analysis and comparison of PVS parameters. It is shown that the parameters for the mathematical model match the experimental parameters obtained under natural operating conditions at remarkable points. This model of PVS will serve as an experimental and laboratory stand in the teaching of students of the University for the subject “Renewable energy sources” (RES).

1. Introduction

The use of renewable energy sources (RES) to generate electricity is an integral part of modern energy in Uzbekistan. If we are talking about energy based on renewable energy, then, first of all, solar energy is mentioned. Since 98.6% of the total energy potential of RES in Uzbekistan is accounted for by solar energy and is considered the most important determining factor when planning the share of RES in the total energy balance of the country [1, 2].

The energy industry provides a favorable field for large-scale use of the unique capabilities of various types of information systems. Since the infrastructure objects of engineering power grids have a significant spatial component and are linked to a specific territory or a specific location, the use of geo-information systems becomes the most relevant [3, 4].

A geographic information system, (GIS) - is a system for collecting, storing, analyzing, and graphically visualizing spatial (geographical) data and related information about required objects.

Geographical location-related data permeates all stages of the process: from field exploration, infrastructure creation, and deployment, generation, storage, transmission, and marketing of electricity [5, 6]. This fully applies to such areas of activity of energy companies as marketing and logistics, compliance with environmental requirements, issues of safety and emergency response, energy-saving and increasing energy efficiency, distribution of capital investments with an assessment of their return.

The purpose of our research is to determine the solar photovoltaic station (PVS) integrated with a local electrical network on the example of a 20 kW PVS installed in the building of the Tashkent State Technical University named after Islom Karimov.

The scientific novelty of the research results lies in the parameters for the mathematical model match the experimental parameters obtained under natural operating conditions at remarkable points.

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This model of PVS will serve as an experimental and laboratory stand in the teaching of students of the University for the Subject "Renewable Energy Sources".

At present, it is very important to provide continuous power to computer and laboratory classrooms, as well as measuring devices, lighting systems based on solar photovoltaic stations, which is one of the main tasks of higher education institutions [7,8].

On the initiative of the Berlin consortium Prethezm Solutions/BAE Batterien (Germany), a 20 kW photovoltaic power station (PVS) was installed on the roof of the main building of the Tashkent State Technical University named after I. Karimov on September 23, 2016, free of charge (Fig.1).

Figure 1. General view of a solar photovoltaic station with a capacity of 20 kW

2. Methods

The PVS includes sixty power lines connected in series and parallel, a three-phase network inverter (SMA, Sunny Tripower 22000TL) with a capacity of 22 kW, three battery voltage inverters (SMA, Sunny Island invertors) with a total capacity of 9.9 kW, a fuse (Batfuse –B. 03), and an electric energy storage system consisting of twenty-four series-connected batteries (AB) with a total capacity of 660 A×hour and a total voltage of 48 V (Fig.2), electric meter, SMA Energy meter and remote control system. The PVS includes a Wi-Fi Router, a solar home controller (Sunny Home Manager), and a data display monitor (Sunny Portal). As shown in Fig. 2 a Solar system configuration consists of the required number of solar photovoltaic cells, usually called photovoltaic modules, connected in series or in parallel to achieve the required output voltage [9, 10]. The basic equation from semiconductor theory, which mathematically describes the *I-V* characteristic of an ideal photoelectric element, is expressed as,

$$I = I_{pv,cell} - I_{o,cell}[\exp\left(\frac{qV}{akT}\right) - 1] \quad (1)$$

Equation (1) of an elementary photovoltaic element does not represent an *I–V* characteristic of a practical photovoltaic system. Elements connected in parallel increase the current, while elements connected in series provide a higher output voltage. Practical photovoltaic modules consist of several connected photovoltaic elements, which can be observed using the diagram (Fig.2).

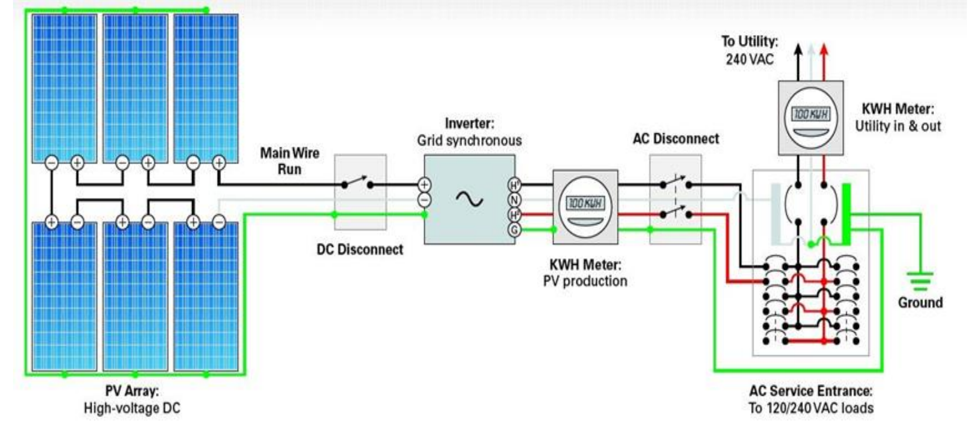

Figure 2. Scheme of low-power PVS

Connecting photovoltaic modules requires the inclusion of additional parameters in the main equation

$$I = I_{pv} - I_0\left[\exp\left(\frac{V+R_sI}{V_ta}\right)-1\right] - \frac{V+R_sI}{R_p} \tag{2}$$

All tables of photovoltaic modules contain mainly the rated open-circuit voltage (Voc,n), the rated short circuit current (Isc,n), the MPP (maximum power point) voltage (Vmp), the MPP current (Imp), the open-circuit voltage coefficient/temperature coefficient (KV), the short circuit current/temperature coefficient (KI), and the maximum experimental peak output power (Pmax,e). This information is always provided with reference to the nominal state or standard test conditions (STC conditions) of temperature and solar radiation. The practical PV device has a series resistance Rs whose influence is stronger in mode when the device works as a voltage source and a parallel resistance Rp with a stronger influence in how a current source works [11,12].

The Isc ≈ Ipv assumption is usually used when modeling photovoltaic devices, because in practical devices, the series resistance is low and the parallel resistance is high [13]. The diode saturation current is set by the formula

$$I_0 = \frac{I_{sc,n}+K_I\Delta_T}{\exp\left(\frac{V_{oc,n}+K_v\Delta_T}{aV_t}\right)-1} \tag{3}$$

The saturation current I0 is highly temperature dependent, so the final effect of temperature is a linear change in the open-circuit voltage according to the practical voltage/temperature coefficient [14]. This equation simplifies the model and eliminates the model error in the vicinity of open-circuit voltages, and therefore in other areas of the I-V curve.

$$I_{pv} = (I_{pv,n} + K_I\Delta_T)\frac{G}{G_n} \tag{4}$$

The relationship between Rs and Rp, the only unknowns from (2), can be found by making $P_{max,m}$= $P_{max,e}$ and solving the resulting equation for Rs, as shown below

$$P_{max,m} = V_{mp}\left\{I_{pv} - I_0\left[\exp\left(\frac{q}{kT}\frac{V_{mp}+R_sI_{mp}}{aN_s}\right)-1\right] - \frac{V_{mp}+R_sI_{mp}}{R_p}\right\} = P_{max,e} \tag{5}$$

$$R_p = \frac{V_{mp}+I_{mp}R_s}{\left\{V_{mp}I_{pv}-V_{mp}I_0\exp\left[\frac{(V_{mp}+I_{mp}R_s)}{N_sa}\frac{q}{kT}\right]+V_{mp}I_0-P_{max,e}\right\}} \tag{6}$$

Equation 2.6 means that for any value R_s, there is a value R_p where the mathematical curve *I-V* intersects the experimental point (V_{mp}, I_{mp}). The goal is to find a value of R_s (and hence R_p) that makes the peak of the mathematical *p–V* curve coincides with the experimental peak power at the point (V_{mp},

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I_{mp}). This requires several iterations until $P_{max,m} \approx P_{max,e}$. Each iteration of the R_s and R_p updates will result in a better solution model.

$$I_{pv,n} = \frac{R_{p+R_s}}{R_p} I_{sc,n} \quad (7)$$

The initial value of Rs can be zero. The initial value of R_p can be set using the formula

$$R_{p,min} = \frac{V_{mp}}{I_{sc,n} - I_{mp}} - \frac{V_{oc,n} - V_{mp}}{I_{mp}} \quad (8)$$

Equation 8 defines the minimum R_p value, which is the slope of the line segment between the short-circuit points and the maximum power points. Although R_p is still unknown, it is certainly larger than $R_{p,min}$ and this is a good initial guess [15, 16].

3. Results and Discussion

According to tables 1 and 2, along with Fig. 3-5, the developed model and experimental data exactly match at the nominal points of the *I-V* curve (the block diagram is shown in Fig.3), as well as experimental and mathematical maximum peak powers are the same. The goal of correcting the I-V mathematical curve at three notable points was successfully achieved [17, 18].

Table 1. Parameters of the KC200GT solar battery when for 25 ^oC, 1000 W/m^2

	MODEL KC220GT - LFBS	PHOTOVOLTAIC MODULE
№	Radiation and temperature of panel	1000 Wm^{-2} AM 1.5 25 ^oC
1	I_{mp}	8.28 A
2	V_{mp}	26.6 V
3	$P_{max.c}$	220.143 W
4	I_{sc}	8.98 A
5	V_{oc}	33.2 V
6	K_v	-0.1230 V/K
7	K_1	0.0032 V/K
8	N_s	54

Table 2. Parameters of the adjusted model of the KC200GT solar battery under nominal operating conditions

	MODEL KD220GT - LFBS	PHOTOVOLTAIC MODULE
№	Radiation and temperature of panel	1000 Wm^2 AM 1.5 25 oC
1	I_{mp}	8.28 A
2	V_{mp}	26.6V
3	$P_{max.c}$	220.143 W
4	I_{sc}	8.98 A
5	V_{oc}	33.2V
6	$I_{0,n}$	9.825×10-8 A
7	I_{pv}	8.214 A
8	α	1.3
9	R_p	415.405 Ω
10	R_s	0.221 Ω

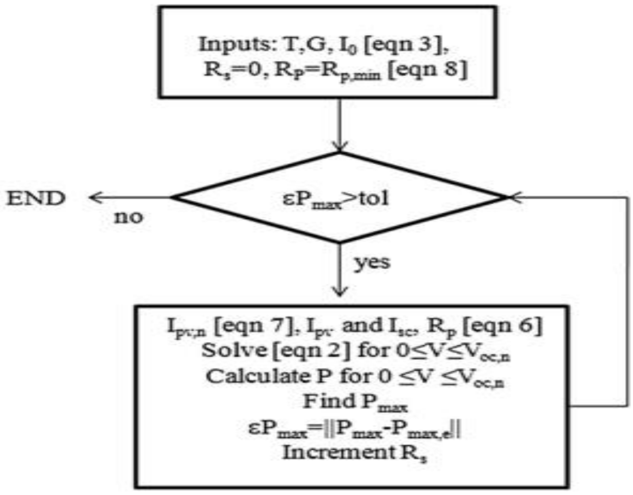

Figure 3. Algorithm of the method used to configure the I-V model

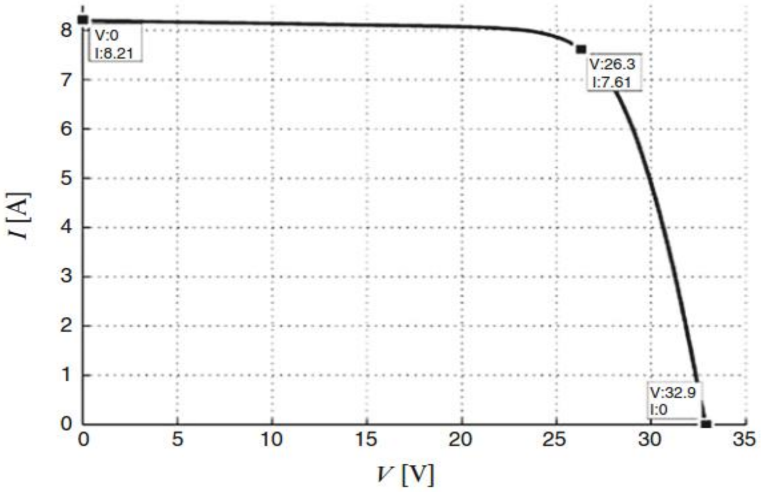

Figure 4. I-V curve adjusted to three notable points

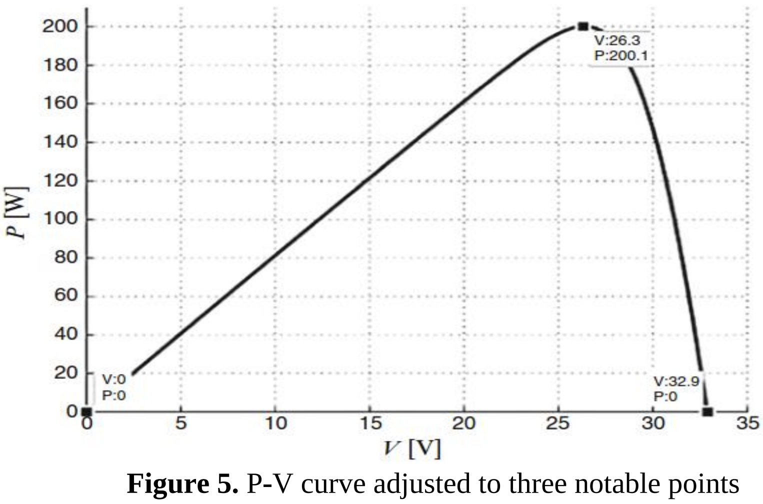

Figure 5. P-V curve adjusted to three notable points

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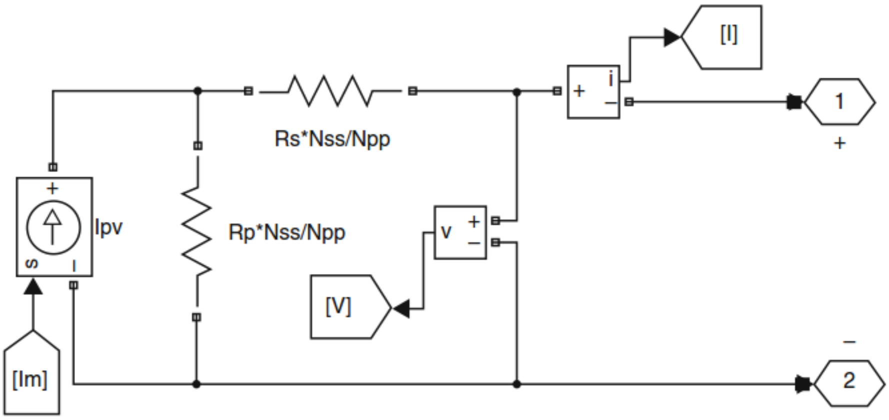

Figure 6. Basic SIMULINK model of an equivalent photoelectric module

Photovoltaic panels (PVP) consist of sixty sequentially connected chains of solar cells based on single-crystal silicon with an efficiency of 19% (manufactured in Germany). Information about the PVP passport data is shown on the back of the module: Sky (AR) 290 W. The electrical characteristics were obtained under standard testing conditions (at a solar radiation flux density of 1000 W/m^2, ambient temperature T=25 ^0C, AM 1.5). The in table 3.

Table 3. Corresponding data are given

Short circuit current I_{sc}	No-load voltage U_{oc}	Maximum current at rated power I_{mp}	Maximum voltage at rated power U_{mp}	Maximum current value I_{max}
9.6 A	39.8 V	9.1 A	32.2 V	18 A

All PVP are installed on special stationary structures that ensure their cooling to ambient air temperature due to air flow circulation [19-31]. For maximum energy performance relative to the trajectory of the Sun PVP is located as follows, the working surface of the photovoltaic cells is oriented perpendicular to the solar radiation flow. It is usually recommended to change the angle of the PVP three times a year to fix the position in the support structure. PVP PVS on the roof of the main building of the Tashkent State Technical University named after I. Karimov installed in a fixed summer position. Therefore, photovoltaic cells produce significantly less electricity during the year.

4. Conclusions

Shown in figure 10, the 20 kW PVS circuit is based on two types of inverters that provide high reliability and efficiency. The Sunny Island battery inverter provides reliable battery charging. The Sunny Tripower network inverter is a transformer – free photovoltaic inverter with two MPPT trackers that converts the direct current generated by the PVS into a three-phase alternating current that is compatible with the network and supplies the alternating current to the public power supply network. The Sunny Tripower inverter can only be operated with photovoltaic batteries that meet the protection class II following IEC 61730, application class A.

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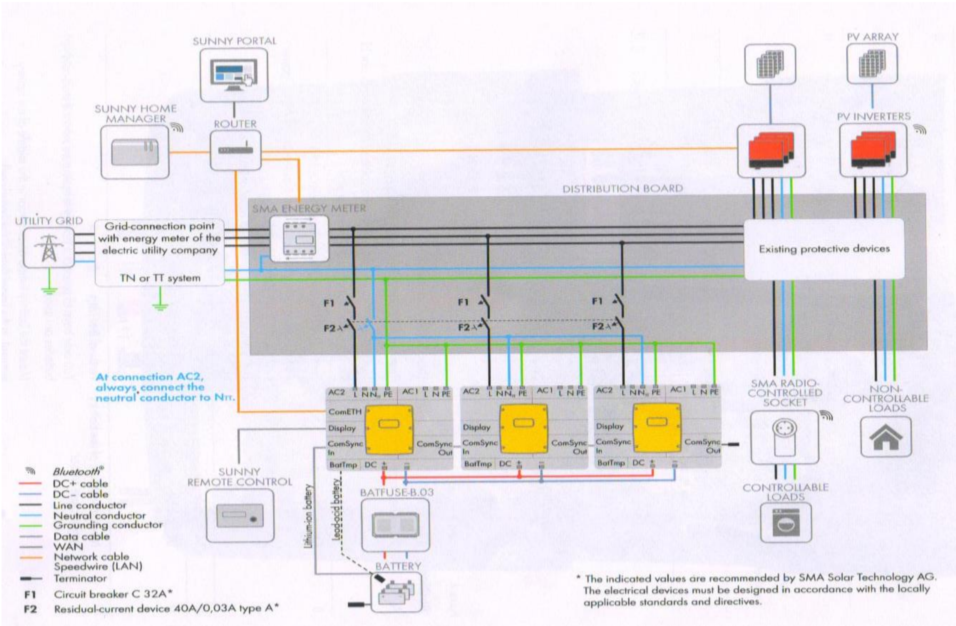

Figure 7. Block diagram of a photovoltaic power supply system with a backup power supply function

If there is a voltage in the electric network and the daytime, the PVS provides additional electricity to consumers via a network inverter (Controllable loads). If the load consumes less energy than the photovoltaic cells produce, the excess energy is directed to charging the batteries. If the load consumes more energy than the photovoltaic cells generate, then the missing energy is taken from the power grid. When the power grid is disconnected (in emergencies), the battery inverters switch to battery operation and form a reference voltage for the network inverter, leaving it in operation. In this case, photovoltaic cells that use solar energy will also supply the network load (local electrical network).

Only in the case of a lack of energy from the photovoltaic battery, the missing energy is taken not from the electrical network, but the batteries. In case of excess energy from photovoltaic batteries and when the battery is fully charged, the battery inverter disconnects the mains inverter until the battery voltage drops to the set value.

This structure can also be used for building Autonomous power systems, but in this case, the power of the battery inverter must be increased to the full load capacity.

The above PVS contains a specialized device Sunny Home Manager, which is used to monitor and control the system parameters, in particular, provides remote control of the parameters of the battery inverter. The system includes an electronic electricity meter and SMA Energy Meter to account for the electricity released to the consumer from the electric network. To ensure the safety of service personnel, an automatic switch is installed in the main electrical circuit of the system, which provides a disconnection of the power supply network in case of accidents.

A more detailed description of SMA Solar Technology AG products, as well as the specification and technical characteristics, can be found on the company's website [4]. Such PVS can be used both for solving local energy problems and global energy problems.

For practical use of electric power, the PVS energy is directed to a load of lighting systems with a capacity of 520 W/h in the educational building of the faculty of Engineering systems. The daily electrical energy consumption of lighting systems is 5.2 kWh. It is also provided to connect computer classrooms, laboratories, and research offices of the Department of "Alternative energy sources" of the Tashkent State Technical University to the load.

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Daily and monthly monitoring are transmitted to the monitor installed in the entrance part of this faculty (Fig.8). Data on the generation of PVS, accumulated energy, and consumed electric energy is recorded in the electric meter.

Figure 8. Monitor for presenting daily and monthly parameters of the PVS (as of 21.04.2019)

Besides, the program instantly calculates the equivalent of saving traditional fuels (firewood, coal, and fuel oil) and emissions of harmful CO2 gas into the atmosphere. Within 38 days, the equivalent of electricity generated was equal to 1420.9 kg of firewood or 679.8 kg of coal, which is equivalent to 568.3 kg of fuel oil, which led to a reduction in emissions of harmful *CO2* gas by 1238 kg to the environment.

To improve the skills of students, PVS serves as a visual demonstration and educational base for students in the field of renewable energy sources.

References

[1] Davletshina M R and Khabirov I K 2008 The use of GIS technology in soil research *In the collection: Agroecological role of soil fertility and modern agrotechnology materials of the International Scientific and Practical Conference* (Bashkir State Agrarian University) pp 52-53

[2] Khaligh Alireza Omer C Onar. P Cm 2008 Energy harvesting: solar, wind, and ocean energy conversion systems *Energy, power electronics and machines Includes bibliographical references and index* pp 9-15

[3] Bakhadyrkhanov M K Valiev S A Zikrillaev N F Koveshnikov S V Saitov E B and Tachilin S A 2016 Silicon-based solar cells with clusters of nickel atoms *Applied Solar Energy* Vol 52 No 4 pp 278-281

[4] Tursunov M N Muminov R A Tukfatullin O F Yuldoshev I A and Abdullaev E T 2011 Photothermal Electric Battery Based on Silicon Solar Cells *Applied Solar Energy* Vol 47 No 1 pp 63-65

[5] RixsiyevT T Tursunov M N Dadamuxamedov S Tukfatullin OF Yuldoshev I A and Yakubova M S 2010 Features of Manufactures Technology of Low-Power Silicon Photoelectric Batteries: Studying Their Parameters *Applied Solar Energy* Vol 46 No 4 pp 248-250

[6] Zikrillaev N F Saitov E B 2014 *Silicon-based PVC with micro barriers of Shottki* (Turin Poplitechnical university in Tashkent) pp 31-33

[7] Abdurakhmanov B A Bakhadirkhanov M K Ayupov K S Iliyev H M Saitov E B Mavlyanov A Kamalov H U 2014 Formation of Clusters of Impurity Atoms of Nickel in Silicon and

Controlling Their Parameters *Nanoscience and Nanotechnology* Vol 4 No 2 pp 23-26
[8] Saitov E B 2016 Technology for producing silicon with nanoclusters. *XIII International Scientific Conference "Solid State Physics" dedicated to the 20th anniversary of the Eurasian National University named after L.N. Gumileva* April 26-28 pp 208-209
[9] Ehsan F A 2016 Impact of the Environment on the Performance of the Photovoltaic Cell *American Journal of Energy Engineering* vol 4 pp 1-7
[10] Skoplaki E Palyvos J 2009 Operating temperature of photovoltaic modules: a survey of pertinent correlations *Renew Energy* № 34 pp 23-29
[11] Kim K A and Krein PT 2015 Reexamination of Photovoltaic Hot Spotting to Show Inadequacy of the Bypass Diode *IEEE Journal of Photovoltaic* vol 5 pp 1435-1441
[12] Saitov E 2016 Study of Quantitative and Qualitative Characteristics of Nickel Clusters and Semiconductor Structures *Journal of Materials Science and Chemical Engineering* №4 pp 30-35
[13] Oh J and G Tamizh Mani 2010 Temperature Testing and Analysis of PV modules per ANSI/UL1703 and IEC 61730 standards *35th IEEE Photovoltaic Specialist Conference* (Honolulu) pp 984-988.
[14] Muminov R A Tursunov M N and Tukfatullin O F 2007 The effect of temperature on the current-voltage characteristics of photovoltaic batteries based on single-crystal silicon *Geliotekhnika* No 4 pp 21-24.
[15] Tursunov M N and Yuldoshev I A 2011 Development of photovoltaic batteries, installations efficiently operating in Central Asia *Problems of energy and resource conservation* (Tashkent) Special issue pp 160-165
[16] Bakhadyrkhanov M K Mavlyanov A Sh Sodikov U Kh and Khakkulov M K 2015 Silicon with binary unit cells as a novel class of materials for future photoener- getics *Applied Solar Energy* vol 51 No 4 pp 258–261
[17] Javoxir Toshov and Elyor Saitov 2019 Portable autonomous solar power plant for individual use *E3S Web of Conferenccs RSES 139* **01087** pp 1-4
[18] Bakhadyrkhanov M K Isamov S B Kenzhaev Z T Koveshnikov S V 2019 Studying the effect of nickel doping of silicon solar cells with a deep p–n junction *Journal of Physics and Technology* Vol 45 No 19
[19] Abdurakhmanov B A Bakhadirkhanov M K Ayupov K S Iliyev H M Saitov E B Mavlyanov A and Kamalov H U 2014 Formation of Clusters of Impurity Atoms of Nickel in Silicon and Controlling Their Parameters *Nanoscience and Nanotechnology* Vol 4 No2 pp 23–26
[20] Abdurakhmanov B A Bakhadirkhanov M K Iliyev H M Isamov S B Saitov E B Mavlyanov A Kamalov H U Saparniyazova Z Sattarov O Sodikov U Kh Zikrillayev N F 2014 Silicon with Clusters of Impurity Atoms as a Novel Material for Photovoltaics *Nanoscience and Nanotechnology* No 4(3) pp 41-43.
[21] Bakhadyrhanov M K Sodikov U X Melibayev D Wumaier T Koveshnikov S V Khodjanepesov K A and Zhan J 2018 Silicon with Clusters of Impurity Atoms as a Novel Material for Optoelectronics and Photovoltaic Energetics *Journal of Materials Science and Chemical Engineering* Vol 6 pp 180–190
[22] Saidov A S Rakhmonov U Kh Leiderman A Yu 2018 Spectral photosensitivity and temperature-independent CVC of pSi-n (ZnSe) 1-x-y (Si_2) x (GaP) y structures *Solar technology* № 4 pp 24-27
[23] Zikrillaev N F Abdurakhmonov B A Saitov E B 2014 The ability to create integrated photocells. *International Scientific Conference Innovations in Materials Science* (Tashkent) pp 78-79
[24] Saitov E 2016 Study of Quantitative and Qualitative Characteristics of Nickel Clusters and Semiconductor Structures *Journal of Materials Science and Chemical Engineering* №4 pp 30-35
[25] Zikrillaev N F Tachilin S A and Saitov E B 2013 Efficient inverters for alternative energy sources *International scientific-practical conference Problems of modern engineering* (Andijan)

IOP Conf. Series: Materials Science and Engineering **883** (2020) 012116 doi:10.1088/1757-899X/883/1/012116

May 16-17

[26] Zikrillayev Nurilla Saitov Elyor Botirov Bozorbek Nasirdinov Bakhodirw Kurbanov Yunus Turayev Farxodjon and Shodiyeva Nozina 2019 Study of the results of diffusion doping technique for producing heterostructures (Si-Ge) using microprobe analysis *Austrian Journal of Technical and Natural Sciences. «East West» Association for Advanced Studies and Higher Education GmbH* No 1-2 pp 56-61

[27] Saitov E B 2019 Technology of manufacturing solar cells with clusters of Ni atoms *Asian Journal of Multidimensional Research (AJMR)* 8 No 3 pp 494-499

[28] Saitov E B 2015 Low-temperature diffusion of Ge S Ni and Mn impurities in silicon to produce photocells *Conference proceedings Energy: management, quality and energy efficiency* pp 532-536.

[29] Bakhadyrkhanov M K MIliev Kh Abdurakhmanov B A Saitov E B Sattorov O E Mavlonov G C Mavlyanov A S Sodikov U H 2014 *X Conf. on actual problems of physics, materials science and diagnostics of silicon, nanometer structures and devices based on "Silicon-2014"* (Irkutsk, Russian Federation) p 74

[30] Bakhadyrkhanov M K Abdurakhmanov B A Saitov Eh B 2013 Study the current-voltage characteristics of the atoms cluster microstructure of nickel-silicon. *Proceedings of international conference dedicated to the seventieth anniversary of Physical-technical institute, SPA 'Physics-Sun' 'Fundamental and applied problems of physics* pp 107-108

[31] Zikrillayev Nurullo and Saitov Elyor 2020 Silicon materials -the future of photovoltaics *LAP LAMBERT Academic Publishing (2020-01-06)* ISBN-13: 978-620-0-50311-4 p 94