Development of an Experiment Control System at a Laboratory Installation of a Photovoltaic Station in a Remote access Mode Based on Web Technologies

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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 10 kW PVS installed in the building of the Tashkent State Technical University named after IslomKarimov. 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 teaching of students of the University for the subject “Renewable energy sources” (RES).
Keywords:solar power plant, solar battery, photovoltaic systems, controller, inverter, battery, photovoltaic station, mathematical model, photovoltaic modules, solar cell parameters, PVS elements, energy sources, RES, geographic information system, solar energy, power supply system, empirical model.

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. Due to the fact that 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 10 kW PVS installed in the building of the Tashkent State Technical University named after IslomKarimov.
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. This model of PVS will serve as an experimental and laboratory stand in 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.

On the initiative of the CHINT Electric (China), a 10 kW photovoltaic power station (PVS) was installed on the roof of the main building of the Tashkent State Technical University named after Islam Karimov on September 23.10.2019, free of charge (Figure1).

FIGURE 1. General view of a solar photovoltaic station with a capacity of 10 kW

2. The degradation of the marineandcoastalecosystems

The PVS includes sixty power lines connected in series and in parallel, a three-phase network inverter (SMA, Sunny Tripower 22000TL) with a capacity of 10 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 40 V (Figure 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 Figure 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 [7, 8]. 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 (Figure 2).

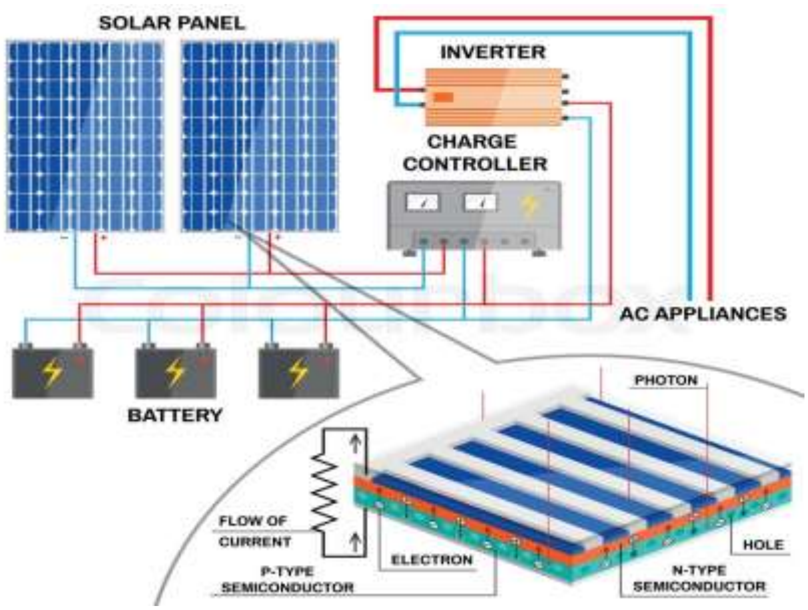

FIGURE2. Scheme of low-power PVS

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

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V+R_S I}{V_t a}\right) - 1\right] - \frac{V+R_S I}{R_p} \quad (2)$$

All tables of photovoltaic modules contain mainly the rated open circuit voltage ($V_{oc,n}$), the rated short circuit current ($I_{sc,n}$), the MPP (maximum power point) voltage (V_{mp}), 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 ($P_{max,e}$). 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 R_s whose influence is stronger in mode when the device works as a voltage source and a parallel resistance R_p with stronger influence in how a current source works [9, 10].

The $I_{sc} \approx I_{pv}$ assumption is usually used when modeling photovoltaic devices, because in practical devices, the series resistance is low and the parallel resistance is high [11]. The diode saturation current is set by the formula

$$I_0 = \frac{I_{sc,n} + K_I \Delta_T}{\exp\left(\frac{V_{oc,n} + K_V \Delta_T}{a V_t}\right) - 1} \quad (3)$$

The saturation current I_0 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.

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

The relationship between R_s and R_p, 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

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

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

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 coincide with the experimental peak power at the point (V_{mp}, 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 R_s 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 [12].

3. Methodology

According to tables 1 and 2, along with Fig. 6-8, the developed model and experimental data exactly match at the nominal points of the I-V curve (the block diagram is shown in Figure 6), 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 [13, 14].

Table 1. Parameters of the KC200GT solar battery when при 25 ^{o}C, 1000 W/m^2.

MODEL KC220GT - LFBS		**PHOTOVOLTAIC MODULE**
№	Radiation and temperature of panel	1000 Wm^{-2} AM 1,5 25 ^{o}C
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 ^{o}C
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

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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

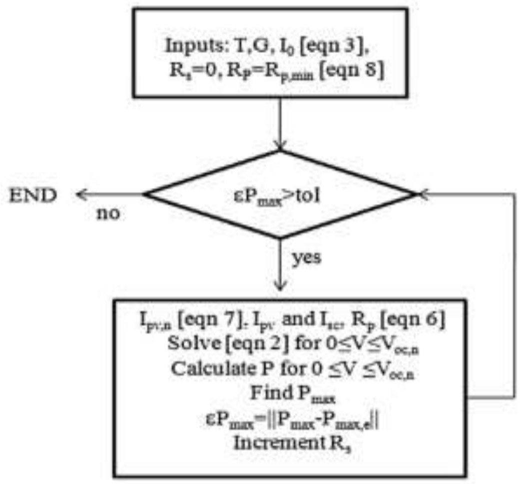

Figure6. Algorithm of the method used to configure the I-V model

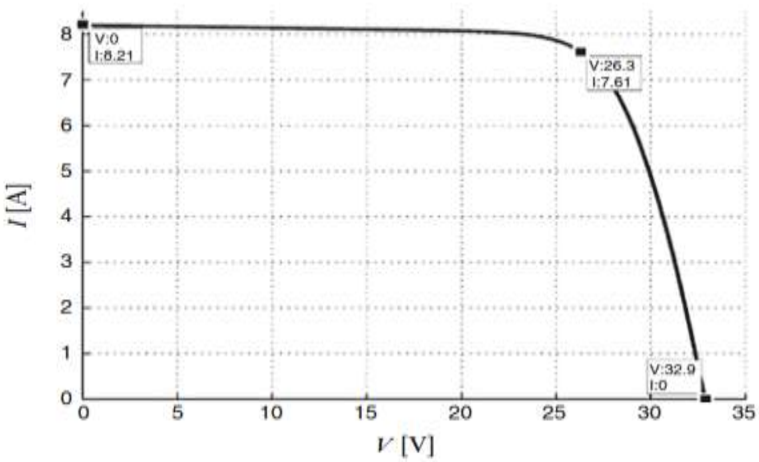

FIGURE7. I-V curve adjusted to three notable points

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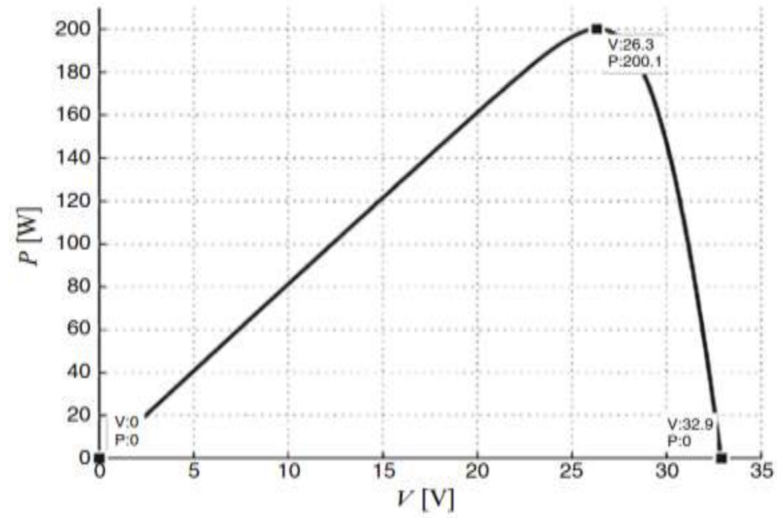

FIGURE 8. P-V curve adjusted to three notable points

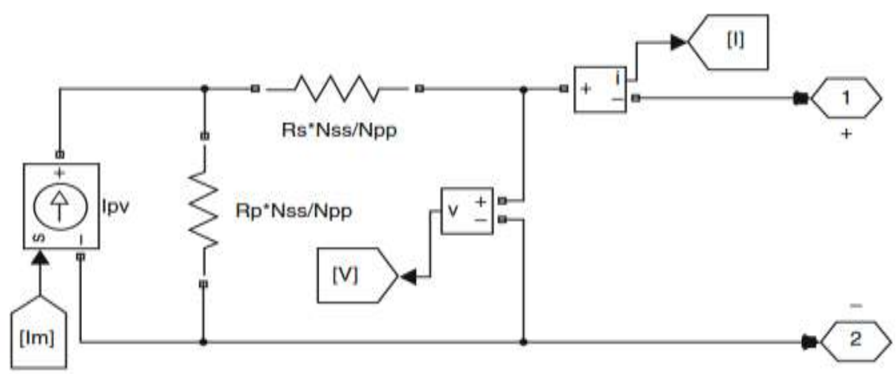

FIGURE9. Basic SIMULINK model of an equivalent photoelectric module

4. Finding

Photovoltaic panels (PVP) consist of sixty sequentially connected chains of solar cells based on single-crystal silicon with an efficiency of 230% (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 ^{0}C, AM 1.5).The Corresponding data are given in table 3.

Table 3.

Short circuit current I_{sc}	No-load voltage U_{oc}	Maximum current at rated power I_{mp}	Maximum voltage at rated power U_{mp}	Maximumcurrentvalue 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 [15, 16]. 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.

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PVP PVS on the roof of the main building of the Tashkent State Technical University named after Islam Karimov installed in a fixed summer position. Therefore, photovoltaic cells produce significantly less electricity during the year.

5. Conclusion

Shown in Figure 10.,the 10 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 in accordance with IEC 61730, application class A.

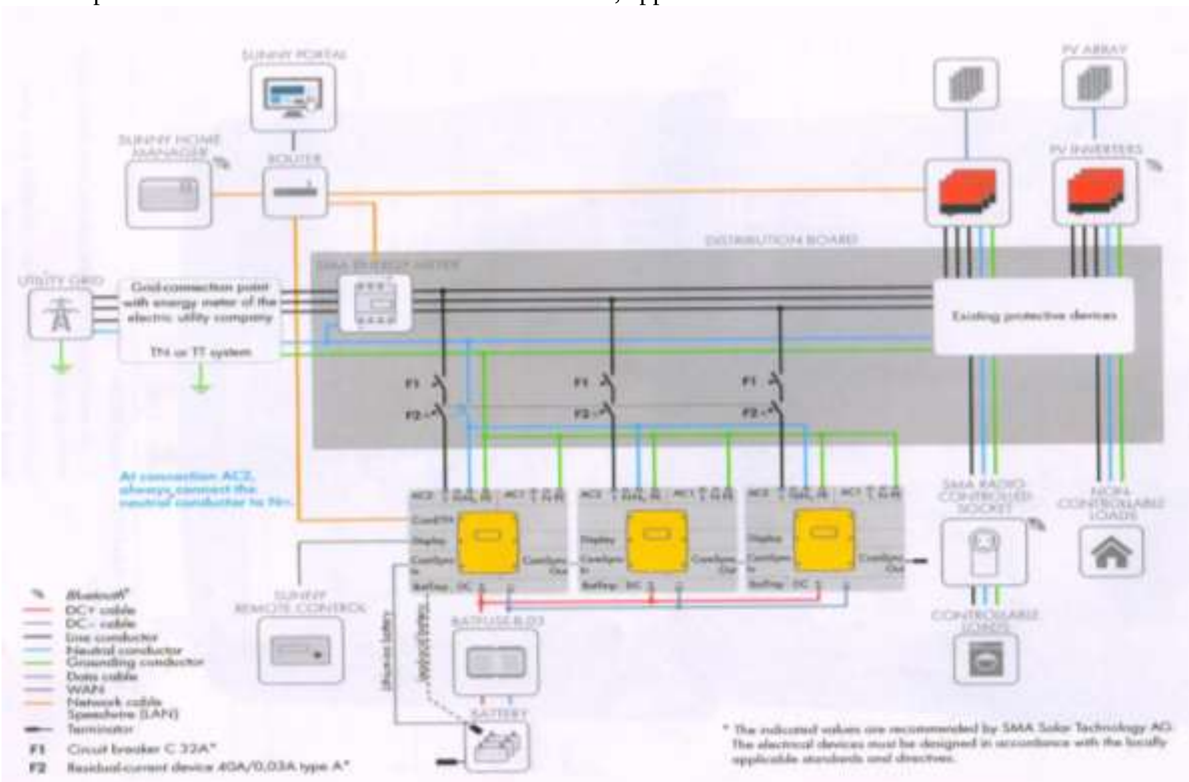

FIGURE10. Block diagram of a photovoltaic power supply system with a backup power supply function.

If there is a voltage in the electric network and in 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 emergency situations), 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 from 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 disconnection of the power supply network in case of accidents.

FIGURE11. Monitor for presenting daily and monthly parameters of the PVS
(as of 21.04.2019)

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 the purpose of practical use of electric power, the PVS energy is directed to the 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, laboratory and research offices of the Department of "Alternative energy sources"of the Tashkent State Technical University to the load.

Daily and monthly monitoring is transmitted to the monitor installed in the entrance part of this faculty (Figure 11). Data on the generation of PVS, accumulated energy and consumed electric energy is recorded in the electric meter.

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In addition, the program instantly calculates the equivalent of saving traditional fuels (firewood, coal and fuel oil) and emissions of harmful CO_2 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 CO_2 gas by 1238 kg to the environment.In order to improve the skills of students, PVS serves as a visual demonstration and educational base for students in the field of renewable energy sources.

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