ENERGETICS

Melnikov Viktor
PhD, Professor, Innovative Eurasian University, Republic of Kazakhstan

Isenov Yermek
MSc in Energy, Innovative Eurasian University, Republic of Kazakhstan

CALCULATION OF PV-GENERATION PARAMETERS AND PRE-PROJECT FORMATION OF THE PV-SYSTEM

Abstract. *The article is devoted to the study of pre-project justifications for the creation of solar power generation facilities, On the example of a solar photovoltaic system the results were obtained, which can be used for real power systems.*
Keywords: *solar energy, photovoltaic system, calculation, financial indicators.*

To provide justification for the project "NewProjectPAVLODAR11-03-21" with a nominal (peak) electric power of PV-system - 3258kW, the following studies were performed. The figure shows a panel of results of calculated volt-ampere generation characteristics of PV module manufactured by AE Solar, type AE400DGLM6-72(1500), 15 modules connected in series and 20 strings in parallel. Abscissa axis - voltage, Volts; ordinate axis - current, Ampere. Characteristics of calculated results of unsorted (uncalibrated) modules by parameters (black); averaged characteristic (green) and scatter of characteristics (dotted line) in the figure shows the following. Maximum power points at solar irradiation of 1000W/sq.m and temperature of 50C are as follows: rated rated power of 109.03 kW; real power of 106.57 kW. The level of power and current losses, respectively: 2,3% и 4,6%. Rated no-load voltage - about 680V, with a variation of 620V to 760V. Design short-circuit current is 225A with a range of parameters from 188A to 230A.

Thus, with other fixed PV module parameters the power, voltage and current parameters of electric PV generation depend on technological deviations during production of this or that batch of PV products, which is demonstrated by the above calculation characteristics. To improve the quality of PV power generation system parameters, it is advisable to select PV panels according to their internal characteristics, ensuring their sorting during the manufacturing of a PV-generating equipment set or specifying a separate option for the appropriate selection of PV panels for a PV module in the equipment purchase order.

Figure 1 shows a panel of calculated PV module generation results from AE Solar, type AE400DGLM6-72(1500) to evaluate the match (or divergence) of the calculated PV string generation parameters from 15 PV modules connected in series. The dependences of stringer current (top left) on voltage differ from the average calculated values and have the following scatter of the calculated parameters of stringer PV generation at temperatures: low temperature - 40C; high temperature - 50C. Estimated value of stringer short-circuit current is 10.4A; estimated value of stringer voltage is from 685V to 710V.

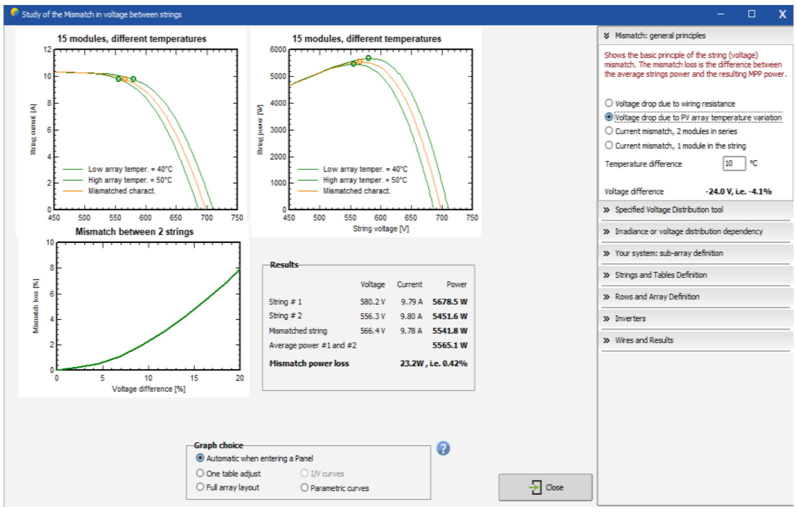

Fig. 1 **Panel of results of calculated generation characteristics of PV module produced by AE Solar, type AE400DGLM6-72(1500), 15 modules connected in series**

The curves (top, center) show the calculated dependences of the string PV-power (ordinate axis) on the value of the string voltage (abscissa axis) with the maximum value of power - 5800W. The dependence (curve below, left) of the relative percentage deviation of PV-losses on the voltage difference, expressed as a percentage, shows that the greater the voltage difference, the greater the deviation of PV-losses: at zero percentage voltage difference the deviation of PV-losses is zero; at 20% voltage difference the deviation of calculated PV-losses is 8.0%.

The main calculated results are as follows. String #1: voltage -580.2V; current - 9.79A; power - 5678.5W. String #2: voltage - 556.3V; current - 9.80A; power - 5451.6W. Difference of calculated electrical parameters of PV-string: voltage - 566.4V; current - 9.78A; power - 5541.8W. Average power of PV-string #1 and #2 - 5565.1W. The mismatch of PV power loss is 23.2W or 0.42%. In addition, the calculated value of the difference of PV-generation voltages under the conditions of the difference of operating temperatures, which is 10C, is 24V or 4.1%.

A generalized view of solar PV generation systems: "PV system - connection to the power system grid and user load" is given below. The required additional pre-design characteristics and calculation data are given below.

New simulation variant

Close Print Export Help

New simulation variant
Detailed System Losses

	ModQual MWh	MisLoss MWh	OhmLoss MWh	EArrMPP MWh	InvLoss MWh
January	-1.211	7.85	3.38	362.7	9.01
February	-0.699	4.53	1.60	209.6	5.64
March	-1.168	7.57	3.29	349.7	9.33
April	-2.053	13.31	7.53	613.0	15.98
May	-2.603	16.87	10.21	776.3	20.41
June	-2.775	17.99	11.00	827.6	21.26
July	-2.393	15.51	9.77	713.3	19.12
August	-2.271	14.72	9.15	677.2	17.77
September	-1.484	9.62	5.58	443.0	12.07
October	-1.347	8.73	4.57	402.5	10.66
November	-0.628	4.07	1.54	188.3	5.37
December	-0.419	2.71	0.82	125.7	3.87
Year	-19.051	123.50	68.42	5688.9	150.46

Fig. 2 **Calculated detailed energy losses (MWh) of PV power generation system**

The main financial and economic indicators of the projected PV power generation system are shown below. The figure shows estimated detailed annual energy losses of PV power generation system (MWh) by months (January-December) and total annual (by rows) for different cases of external factors (by columns):

depending on the technological level and quality of manufacturing PV-module - total annual result (-19.051MWh) - first column;

accuracy loss from model array mismatch - total annual result (123.50MWh) - second column;

ohmic losses - total annual result (68.42MWh) - third column;

electric power generation of the model array - total annual result (5688.9MWh) - fourth column;

global PV-inverter losses - total annual result (150.46MWh) - fifth column.

The figure shows the calculated values of specific capacities (kWh/sq.m.) from the effect of the optical factor of the PV power generation system by months (January-December) and the total annual (by rows) for different cases (by columns):

for the global horizontal PV-module irradiation - total annual result (1232.9MWh/sq. m.) - first column;

for the global incident array in the plan - total annual result (1998.1MWh/sq.m) - second column;

for the coefficients, as shown in the figure, the average annual results-the third (average value is 1.621), the fourth (average value is 1.000), and the fifth (average value is 0.993) columns, respectively.

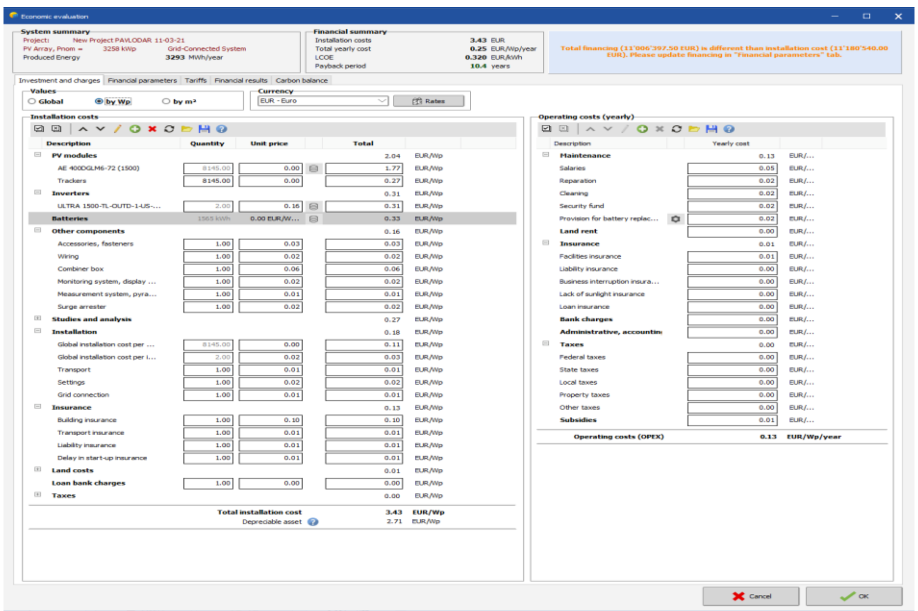

Fig. 3 **Main calculated indicators of financial results for the projected target PV**

The figure shows the main design parameters of the projected PV facility, referred to 1.0 Wpc.

Basic data of the PV system.

Project name: NewProjectPAVLODAR11-03-21. Nominal (peak) electric capacity of PV-generating system - 3258kW. Generation of electric energy, annual - 3293.0MWh. The projected PV-system is connected to the electric power system networks.

Key financial indicators.

The total installation cost of the PV power generation system is 3.43€/ Wpc. Total annual costs - 0.25 €/ Wpc /year. Operating costs - 0,320 €/kWh. Investment payback period - 10,4 years.

Global estimates.

PV modules. Total cost of PV modules with PV trackers: 2.04 €/ Wpc. Total cost of PV modules of type AE400 GLM6-72 (1500): 1.77 €/ Wpc; number of PV modules: 8145. Total cost of PV trackers -0.27 €; number of PV trackers - 8145.

PV inverters. Total cost of PV-inverters - 0,33 €/ Wpc.The total cost of energy storage batteries is 0.33 €/Wpc.

Other components. Total cost of components - 0,13 €/ Wpc. The list and design costs of the main components are shown in the figure above.

Study and analysis. Total cost - 0,27 €/ Wpc.

Installation, mounting, etc. Total cost - 0,18 €/ Wpc.

Insurance of buildings, constructions, transport and other design objects. Total cost - 0,13 €/ Wpc.

Land. Total cost - 0,01 €/ Wpc.

Total system cost - 3,43 €/ Wpc.

Depreciation cost - 2,71 €/ Wpc.

Operating costs (annual, OPEX) - 0,13 €/ Wpc /year. Technical service (operation) - 0,13 €/ Wpc. Including: wages - 0,05 €/ Wpc /year. Other indicators are given in the figure above.

The figure shows the main calculated indicators of the projected PV-object, which has the following basic (global) data. Project name:

NewProjectPAVLODAR11-03-21. Nominal (peak) electric capacity of PV-generating system - 3258kW. Generation of electric energy, annual - 3293.0MWh. The projected PV-system is connected to the electric power system networks.

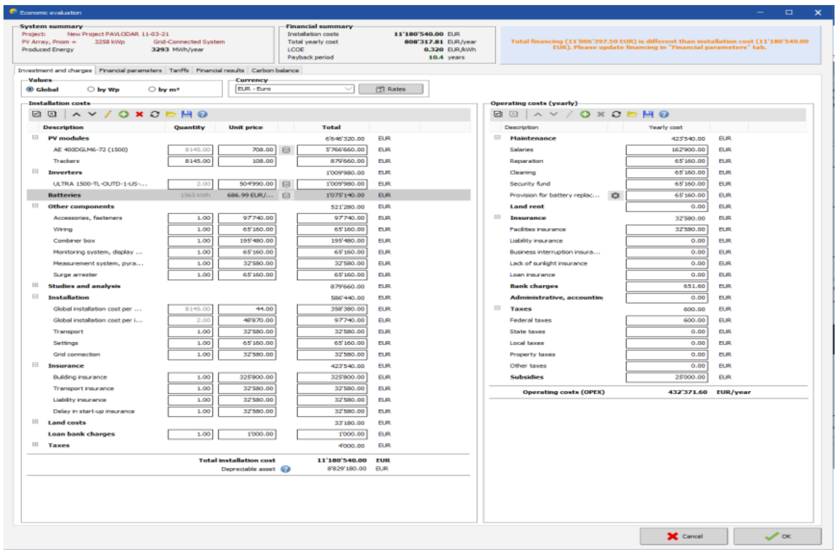

Fig. 4 **Calculated figures of the main results of the projected PV-object**

Key financial indicators.

The total cost of installing the PV power generation system is 11180540.0 €. Total annual costs - 808317,81€. Operating costs - 0,320 €/kWh. Investment payback period - 10.4 years. Global calculation indices.

PV modules. Total cost of PV-modules with PV-trackers: 6646320.0 €. Total cost of PV-modules type AE400 GLM6-72 (1500) - 576660,0 €; unit cost of PV-module type AE400 GLM6-72 (1500) - 708,0 €; number of PV-modules - 8145. Total cost of PV trackers - 879660.0 €; unit cost of PV trackers - 108.0 €; number of PV trackers - 8145.

PV inverters. Total cost of ULTRA-1500 TL type PV inverters - 1009980.0 €; unit cost of ULTRA-1500 TL type PV inverters - 504990.0 €; number of PV inverters - 2.

Batteries. Total cost of energy storage batteries - 1075140,0 euros; unit cost of batteries - 686,99 €; capacity of batteries - 1565,0 kWh.Other components. Total cost of components - 521280,0 €. List and project costs of the main components:

Study and analysis. Total cost - 879660,0 €.

Installation, mounting, etc. Total cost - 586440,0 €.

Insurance of buildings, structures, transport and other design objects. Total cost - 423540,0 €.

Land. Total cost - 33180,0 €.

Taxes. Total cost - 4,000.0 €.

Total cost of the system - 11180540,0 €.

Depreciation costs - 8829180,0 €.

Operating costs (annual, OPEX) - 432371,6 €. Technical service (maintenance) - 423540,0 €. Including: salary - 162900,0 €. Other indicators are shown in the figure above.

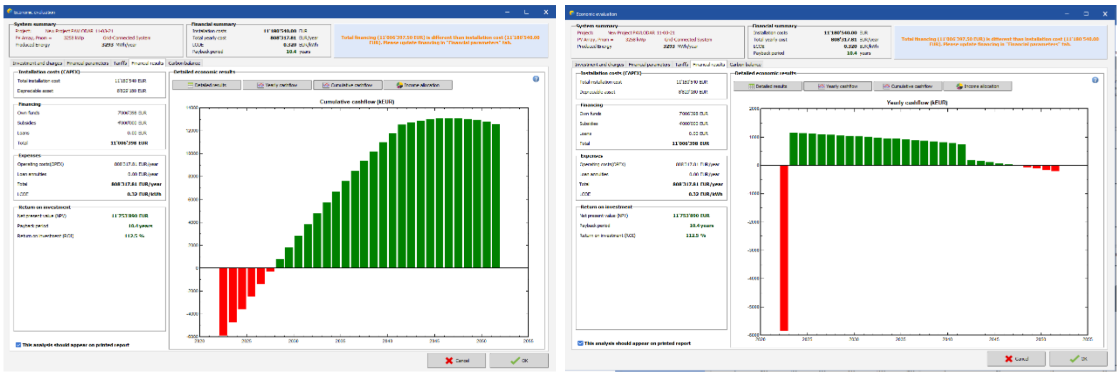

Fig. 5 **Estimated financial performance indicators for the projected facility**

Figure 5 shows the estimated financial flows (accumulated), expressed in thousands of euros. From the beginning of the project (2022) and for 6 years, the financial flows highlighted in red have a negative value, decreasing to zero by the end of the sixth year, i.e. by the end of 2027. Then, starting in 2028, as shown in green, the financial flows have a positive value. And for the next 14 years have a steady growth with a constant value, including 2041. After that, there is a "plateau" until 2047, and then a decrease in the accumulated financial flows, until the estimated end of operation in 2052.

The figure (right) shows the estimated financial flows (annual), expressed in thousands of euros. From the beginning of the project - 2022 - the annual financial flows, highlighted in red, have a negative value. Then, starting from 2023, as shown in green, the financial flows have a positive value. And over the next 19 years, they have a steady, constant value towards a slight decline, including 2042. After that, starting in 2043, there is a sharp, almost 70% annual decline until 2047, and then a decline with negative annual financial flows, until the estimated end-of-life of 2052.

Pre-project proposals for the main scheme components of PV electric generation systems are shown below.

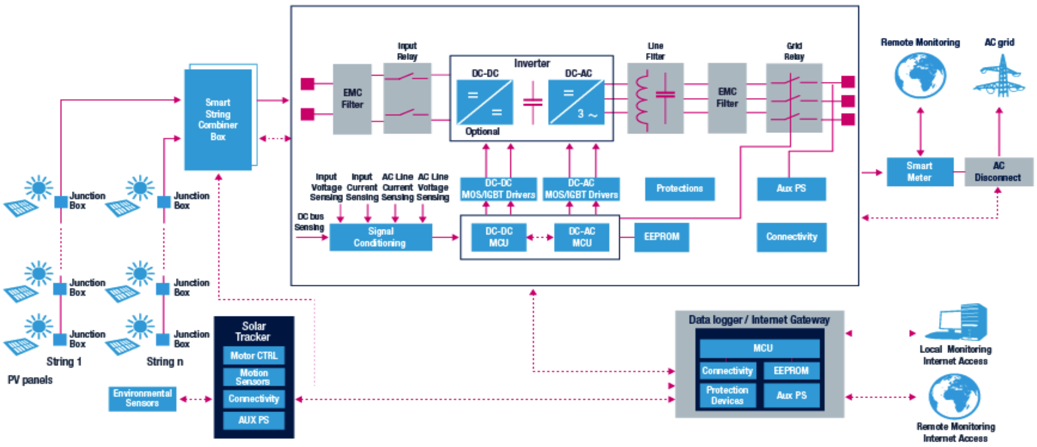

Fig. 6 **Main functional components of PV electric generation systems**

The figure shows the basic functional layout of solar PV electric generation systems.

The scheme in the figure above has a central inverter, the electrical power of which is determined by the power of all connected strings of solar panels. The input circuits of the central inverter are connected to a DC-DC converter. Its power is determined by the power of all connected PV strings.The functional diagram of the solar PV generation system using a smart string combiner box is shown in the figure. The system provides the generation of electrical energy into the three-phase AC power grid.

This connection is provided through a controlled inverter. In this case, the output parameters of the inverter: the output current frequency, output voltage level, output voltage phase symmetry must strictly match the parameters of the power system network. For this purpose the system of information-measuring smart control unit. The control of the output parameters of the inverter is continuously tested for compliance with the high-speed and through the communication system. For example, via closed and secure internet communication channels; this process information is transmitted to the relevant "administrators" as shown in the figure.

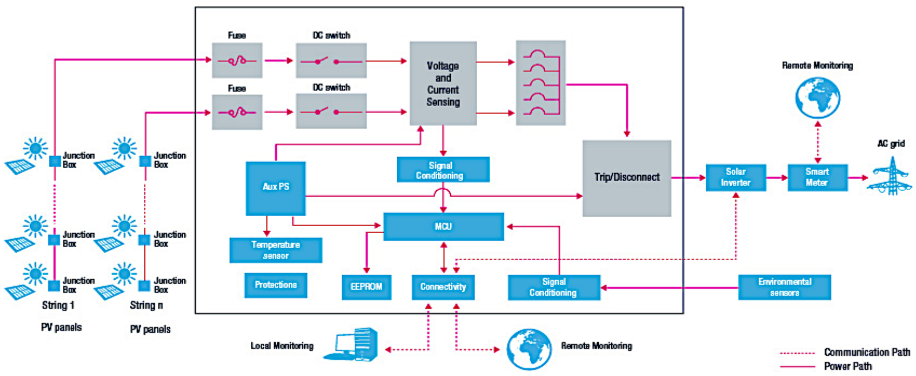

Fig. 7 **Functional diagram of a solar PV power generation system using a smart string combiner box**

The input of the controlled inverter is fed with DC voltage electrical energy generated by the solar PV system from the output of the smart string combiner box. This equipment, whose complex of components is indicated in the figure by a solid rectangular line, "collects" the electrical energy from all PV strings. The functional layout of the smart string combiner box is as follows. This layout allows the selection of power electronics components in the form of PV inverters in a wide power range from less than 10kW; from 10kW to 100kW; from 100kW to 250kW and up to power over 1.0MW.

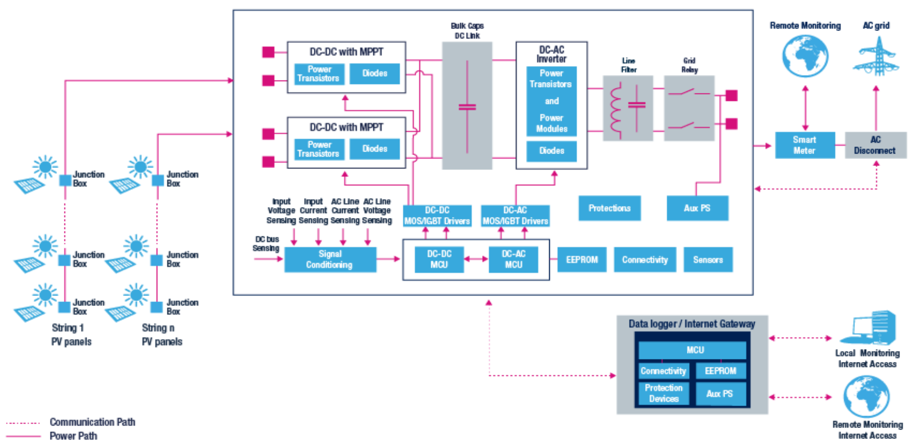

Fig. 8 **Functional diagram of a solar PV generation system using a central PV inverter and PV strings**

As an example of power components recommended by the developer, the following are examples of power transistor modules with different parameters: FF600R12ME4_D11 (voltage 1200V; current 600/1200A; built-in protections; low losses; "soft" switching mode); FF600R12IE4 (voltage 1200V; current 900/1800A; integrated protections; low losses; "soft" switching mode). More detailed characteristics and properties are given in the supplier's technical documentation.

References:

1. U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20- 68925. https://www.nrel.gov/docs/fy17osti/68925.pdf.
2. EIA. 2020. "Annual Energy Outlook 2020 with Projections to 2050." AEO2020. Annual Energ Outlook. Washington, D.C.: U.S. Energy Information Administration. https://www.eia.gov/outlooks/aeo/pdf/ AEO2019 .pdf.
3. David L. King, William E. Boyson, Jay A. Kratochvil Sandia Model - Photovoltaic Array Performance Model SAND2004-3535 report, Unlimited Release, August 2004 Sandia National Laboratories, Photovoltaic System R&D Department Albuquerque, New Mexico 87185-0752 Available on http://energy.sandia.gov