PRELIMINARY TECHNICAL DESIGN – PROJECT SOLAR 5 000 +

PV system with capacity of 10 kW – 1000kW

Users: Legal entities

Facility: PV system with capacity of 10 kW -1000Kw

Location: Montenegro

Investor: Elektroprivreda Crne Gore A.D.

Designer: Greener d.o.o.

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1. TERMS OF REFERENCE

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Faced with necessity of as fast and efficient energy transition as possible, transition of electricity generation from fossil fuels to renewable energy sources, and being aware of the fact that Montenegro has extraordinary potential for electricity generation on the principle of photovoltaic effect, EPCG launches an initiative for the implementation of the Solari 5000+ Project (hereinafter referred to as 5000+) for individuals and legal entities.

This Project includes:

1. Procurement of funds for financing the project 5 000+.
2. Development of technical design, technical specification and procurement of equipment for the needs of the project.
3. Installation of grid-connected (on grid) photovoltaic systems with the capacity of 10kW to 1000 kW on the structures owned by individuals and legal entities
4. Providing subsidy for the project financing by EPCG in the amount of 20%.

Committee for investments in the energy sector will constitute **Project Board**, the body to be in charge of the project implementation and consisted of the representatives of the Government of Montenegro, Eco Fund, Faculty of Electrical Engineering, CEDIS, Elektroprivreda Solar Gradnja, and EPCG. The Project Board will carry out the following:

a. Develop the Feasibility Study;
b. Develop Preliminary-Technical Design;
c. Launch Public invitation for providing funds for project 5 000+. As the European and world banks allocate significant funds for financing 'green projects', Public invitation is to be conceptualized in such a manner so as to ensure the maximum possible amount of grants (non-refundable funds). Maximum loan amount would amount to 70 million Euros;
d. Financing, i.e. crediting of the project 5 000+ should, if possible, ensure that the users pay the loan installments for the solar equipment, which will be sized in such a way as to cover all the users' annual electricity requirements, on an annual basis;
e. Control of the technical specifications for the tender procedure for the procurement of equipment required for the implementation of 5000+ project;
f. Carry out procurement of necessary equipment – Public invitation;
g. Organize a strong and timely media campaign to encourage users to participate in the project;

h. Public invitation for the citizens-users and legal entities meeting the invitation requirements;
i. Defining the necessary procedures for preparation of technical documentation and execution of works.

Value of the project may be maximum 70 million Euros and total installed capacity may amount to the total of 70 MW.

One of the basic elements of this Project implies providing such a method of financing so as to enable for the loan instalment of the project participant, a physical entity, regarding repayment of the installed equipment, not to exceed the amount of former costs for consumed electricity, not counting the engagement of network capacity (maxigraph).

Regional representation of customers must be taken into account during project implementation, without endangering economic feasibility of the project.

All the customers are to be represented evenly (paying attention to their former consumption expressed in kWh), without endangering technical features of PV systems and financial feasibility of the project.

In order to implement the Project, Preliminary-Technical Design which will be in compliance with the basic assumption of the Terms of Reference is to be developed.

The Preliminary-technical design is to envisage the possibility of using the system for energy storage (batteries) in the future.

It is necessary to prepare a comprehensive Feasibility Study, including variability of basic parameters, installed power of PVSE, equipment prices, number of sunshine hours, and prices of electricity on the electricity exchange, interest rates for crediting the project, with and without subsidies.

When preparing the Preliminary Technical Design and the final Feasibility Study, it is necessary to consider the values of the historical consumption of the structures in question, on the basis of which it is necessary to form the PV system capacity sufficient to completely cover the needs for electricity on an annual basis. In addition, it is necessary to analyze the ratio of the approved connection capacity of the system and the capacity of the proposed PV system (in accordance with paragraph 1 of Article 96 of the current Law on Energy) as well as roof surfaces available for PV modules mounting.

When determining the quantities and capacities of the inverter devices that will be used in the 5000+ project, the flexibility in creating specific technical solutions should be ensured in order to dimension the generation capacity that covers the end user requirements as precisely as possible.

Considering solar potential at the territory of Montenegro, as well as population density for the needs of this Project, the following regional representation is suggested for installation of the planned photovoltaic systems:

- 40% installations south – coast,
- 40% installations central part,
- 20% installations north.

The Preliminary Design should propose a percentage distribution of the sub-construction elements for PV modules installation, analyzing the types of roof coverings on the facilities for which owners have expressed interest in equipping with a PV system.

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Chairman of the Board of Directors

epcg

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2. INTRODUCTION

Subject matter of this document refers to the technical solution of PV systems for electricity generation, which are planned to be installed on the rooftops of facilities owned by legal entities. The total planned power of all PV systems that will be realized by the project is 70 MW. The facilities where the construction of PV systems is planned are hotels, restaurants, commercial facilities, sports halls, warehouses, shopping centers, gas stations, public facilities (schools, hospitals, administrative buildings) and all other facilities where one or more legal entities carry out activities. The document is aimed at defining the basic technical criteria for the project SOLAR 5000+ development and providing guidelines for the implementation thereof.

The aim of the decentralized installation of PV systems is to meet one's own needs of the final consumer of electricity. A prerequisite for installation is the existence of an available roof surface for photovoltaic modules installation, which must be fully exposed to the sun, without shading from the surrounding buildings, trees, ventilation exhausts, chimneys and other objects. An additional condition is the existence of active electricity consumption at the location where the PV system is being built, especially in the period when electricity is being produced. The system dimensioning is done based on historical data on the consumption of the facility, on an annual basis.

The electricity generation system is planned to be connected to the existing power system infrastructure, in accordance with the conditions for connection issued by the distribution system operator (DSO). The connection point of the photovoltaic system to the distribution system must be located at the ownership border, on the facade of the building, or another suitable place outside the building, accessible for reading of technical parameters, control and manipulation by skilled services of CEDIS.

According to the existing Energy Law (Article 96), this concept establishes the so called prosumer (produce and consume) concept in Montenegro. The prosumer concept implies active exchange of electricity with distribution system whereby user delivers surplus to the distribution system and withdraws electricity from it according to the building demands. Energy balances are compiled on April 1 of the current year, after which the calculation of delivered and received electricity is made.

The PV systems capacities will be defined after the technical analysis of the facility and will be in the range of 10-1000 kW.

Sizing of a system capacity should be done in line with the following criteria:

1. Actual electricity demands of a facility – analysis of a consumer's profile;
2. Available rooftop surface and its condition;
3. Approved switching capacity of a facility and technical possibilities of connecting to the distribution system.

Figure 1: Installation of PV system on the roof of the commercial facility
(source: www.carolinasolarquote.com)

By analyzing historical data on the consumption of commercial facilities that are available to the supplier (EPCG), as well as by taking a detailed look at the conditions in which such a system will function (microlocation, orientation and tilting of the roof surface, shading from other buildings), it is possible to determine the photovoltaic system capacity that would cover all the electricity needs of the customer on the annual basis under net measurement condition.

2.1 TECHNICAL DOCUMENTATION DEVELOPMENT

In accordance with the Law on Planning and Construction of Buildings (Article 223), PV systems with a capacity of 30 kW up to 5 MW are classified as local facilities of general interest. For these facilities it is necessary to develop the Main design of the photovoltaic system with the accompanying Studies related to the static stability analyses of the facility after PV modules installation as well as fire protection.

Before technical documentation preparation, it is necessary to obtain the Urbanistic - Technical Conditions (UTU) and conditions for connection to the distribution system. These conditions may be joined in one document. Technical documentation preparation has to be done according to the valid Rulebook on the method of preparation and content of tehnical documentation ("Official Gazette of Montenegro", no. 044/18 dated July 6, 2018).

After the technical documentation development, the project should be reviewed by the authorized institution and all necessary approvals have to be obtained.

Obtaining a positive review report is one of the last administrative steps, after which the construction application is made and the implementation of the investment begins. After checking the installation and putting the system into operation, the Agreement is concluded between the user and the supplier on the exchange of electricity.

2.2 ANALYSIS OF THE COMMERCIAL FACILITIES CONSUMPTION

Analyses of the historical data on the consumption of commercial facilities submitted by Investor EPCG, (total number of analyzed consumers 1.245), consumers' groups were classified according to the approved capacity of the facility, which is also the maximum power of the photovoltaic system that can be connected at the location in question. The following table shows the results of the analysis.

Table 4: Analysis of the number of customers and proportional distribution per consumption category

ANALYZED CONSUMERS' STRUCTURE				
Approved capacity	**Number of consumers**	**Percentage share**	**Average annual consumption**	**Total annual consumption**
Up to 33 kW	990	79.52%	48 481 kWh	**47.996 GWh**
From 30 to 50kW	45	3.61%	78 366 kWh	**3.526 GWh**
From 50 to 100 kW	51	4.10%	154 089 kWh	**7.858 GWh**
From 100 to 150 kW	54	4.34%	188 443 kWh	**10.175 GWh**
From 150 to 200 kW	42	3.37%	392 932 kWh	**16.503 GWh**
From 200 to 250 kW	41	3.29%	256 136 kWh	**10 501 GWh**
Over 250 kW	22	1.77%	394 912 kWh	**8 688 GWh**
Total	**1245**	**100%**		**105.24 GWh**

It is estimated that the average consumption of companies will constantly increase.

Furthermore, an analysis of the required PV system capacity to cover the entire consumption of electricity was performed assuming that each of the mentioned facilities has sufficient available roof surface for the installation of PV modules (since the designer didn't have precise information about the available roof surfaces of the facility, this assumption was adopted).

The calculation of the PV system capacity is determined by simply dividing the total annual consumption of the facility by 1250, because on the basis of all previous analyses of the solar potential of defferent locations at the level of Montenegro, it is possible to define the average specific annual generation of electricity from 1 kW of the installed PV system, which is 1250 kWh/kW (the average value was taken with a margin of approx. 10% so that the generation result would in any case meet the projected values).

The greatest number of analyzed consumers (>90%) needs a PV system whose power is in the range of 10 - 1000 kW, and this project proposes the acquisition of PV equipment, the combination of which can create all the mentioned systems. **In this way, the absolute flexibility will be achieved in adapting the technical solution to the needs of the facility.**

2.3 TECHNICAL PRECONDITIONS FOR INSTALLATION OF A PV SYSTEM

In order to implement the rooftop solar system it is necessary to provide the main technical preconditions as follows:

- the available rooftop area for installation of PV modules (available surface means the roof surface that is free of ventilation outlets, chimneys, skylights or any physical obstacles as well as shadows from the facilities that are located on the roof or in the immediate vicinity of the main facility); rooftop area must be tilted towards the south (southeast or southwest) where the range of the azimuth angle is 90° - 270° (seen from the north, clockwise); The minimum inclination (altitude) angle of the roof surface is 5°;
- connection to the distribution system in accordance with the Conditions of the distribution system operator (DSO) respecting all technical restrictions;

For some facilities (40%), it is necessary to increase the facility approved capacity so that a PV system can be connected at the location, which will fully meet the requirements of the user. The initiative to increase the capacity has to be submitted to the Distribution system operator only if it is determined that there is sufficient available area for the installation of all the required photovoltaic modules. **The procedure for increasing the approved facility capacity needs to be adjusted in administrative and technical terms so to provide the distribution system operator with the most accurate information from the field.**

As for the legal aspect, the user is obliged to possess a valid Real estate folio of a facility planned for a PV system installation, i.e. without any encumbrance on property.

3. TECHNICAL SOLUTION

3.1 Connection of facility to the distribution system

In order to achieve flexibility in the preparation of technical solutions, the combined use of 10 kW, 20 kW, 50 kW and 100 kW inverters is proposed. In this way, it is possible to optimize the technical solution and more precisely adjust the production capacity to the needs of the end user for electricity. The number of inverters was determined by a detailed analysis of registered users and their needs to cover the own consumption of the facility.

The table showing the required amount of inverters is as follows:

Inverter type	Inverter 10 kW	Inverter 20 kW	Inverter 50 kW	Inverter 100 kW
Qty	500	800	280	350
Total	**70 MW**			

The connection point has be determined by the designer and all in accordance with the recommendations and conditions for connection issued by the distribution system operator. It can be a cabinet that is placed on the facade of the facility (or on the facade of the substation), but also the low-voltage block of the existing transformer station if the conditions on the terrain satisfy the application of this solution. In every case, in accordance with the conditions of the DSO, at the " the power plant gate" it is necessary to provide a control meter for reading of the total electricity generated. The meter receives data on electricity via electricity transformers X/5A, and the transmission ratio must be determined depending on the capacity of the system.

For the systems capacity up to 30 kW, it is necessary to provide basic relay protection (undervoltage/overvoltage, underfrequency/overfrequency, presence, sequence and asymmetry of phases), while for the systems capacities over 30 kW, the use of a multifunctional relay with integrated ROCOF (Rate of change of frequency) and VVS (Voltage Vector shift) protection. **The protection setting has to be performed by a certified person, together with the relay protection engineers of the distribution system operator.**

After the system capacity defining, it is necessary to dimension the power cables at the lines - inverter - RO-AC-PV AND RO-AC-PV - connection point.

Protection on the DC side is achieved by using a DC surge arrester integrated in the inverter device. Overcurrent protection on the DC side is achieved, if necessary, by using DC distribution line fuses that are integrated in the inverter device. When more than two strings are connected to the same MPPT, it is necessary to provide overcurrent protection, because in the event of a failure on one string, the other two connected in parallel to it supply the failure spot, and this position may overheat and possibly cause a fire. The technical recommendations define that the rated current of the distribution line fuse has to be in the range 1.5xIsc < x < 2.4 xIsc, where Isc is the short-circuit current of the PV module declared by the manufacturer. With the proposed system configurations, there is no case where more than two strings are connected in parallel to the same MPPT device, and it is not necessary to provide overload protection on the DC side of the system. However, it is suggested to use integrated distribution line fuses with a rated current of 20 A as additional system protection.

In accordance with the valid standard MEST EN 50549-1 as well as the technical recommendations of DSO, the inverter protection setting has to be performed in accordance with the values from the following table:

Table 5: Values according to which it is necessary to adjust the protection of the PV system

Protective function	**Limitation**	**Time of action**
Undervoltage U<	195 V	1,5 s
Overvoltage U>	253 V	0,2 s
Subfrequency f<	47 Hz	1 s
Overfrequency f>	51Hz	0,2 s
Permanent overvoltage (UNOM_max medium 10min)	253 V	3 s
Protection against island mode operation(Vector Jump)	7°	currently
Protection against island mode operation(df/dt)	1 Hz/s	currently
Voltage setting for automatic reconnection after a power outage	0,85xUn ≤ U ≤ 1,1xUn	
Setting the frequency for automatic reconnection after a power outage	49,5 Hz ≤ f ≤ 50,1 Hz	
Reactivation time after a network outage	60 s	
Active capacity gradient after reconnection	10 % Pmax / min	
Permanent direct current injection	0.5% of the rated output current of the inverter or 20mA	

Part of the technical requirements is achieved by setting the relay protection that reacts to the coil of the contactor for separating the PV system from the distribution system, while the other part is achieved by choosing an inverter that has been tested in accordance with the standards that prescribe the integrated protections that the device must have in order to function normally.

All distribution cabinets in which the energy equipment for connecting the photovoltaic system is placed have to be marked with the prescribed warning signs that the location is power supplied by two sides. It is very important to ensure the safe integration of PV systems by introducing users with the elements of the system and the necessary protection measures.

3.2 Selection of PV modules

PV system equipment is continuously being improved, whereas efficiency of certain elements is constantly increasing. It is proposed to use monocrystalline PV modules in order to implement this technical solution, which implies implementation of PV systems on rooftops of residential buildings. Monocrystalline silicon PV modules are characterised by higher mechanical resistance compared to polycrystalline PV modules, as well as by higher efficiency, better temperature coefficient, longer service life, lower impact onto generation due to high temperatures and decrease in irradiation. These PV modules are more expensive than polycrystalline modules; however, all the above stated advantages justify the investment, especially considering service life of 25 years, which represents service life of the system.

Currently there are monocrystalline PV modules of various size and power in the market. Based on detailed analysis of modules’ dimensions, their weight and possibilitz of installation at heights, and having in mind that the Project includes construction of higher capacities systems (up to 1MW), use of module with the capacity of 540 Wp, which is slightly bigger in dimensions, is justifiable. Detailed technical characteristics have been defined after detailed analysis of 10 most common modules in the market. Minimum efficiency of this module amounts to 20.65%. Reduction in the efficiency during service life amounts to 2% in the first year and 0.55% during each following year, due to degradation of PV modules. It is expected that PV modules operate with minimum efficiency of 84.8% after 25 years. Approximate dimensions of 540 Wp PV modules are 2278x1133x35 mm, given that they vary depending on the manufacturer. PV modules must be made using half-cell technology and they must have Anti PID (Potential Induced Degradation) protection.

The typical guarantee for PV modules is 12 years for the product and 25 years for performance of PV cells. The same guarantees should remain in tender documents.

Basic features of the proposed PV module are given in the following table:

Monocrystalline PV module 540 Wp	
Module capacity (STC*)	540 Wp
Voltage Vmpp (STC)	31,2 V – 42,15 V
Current Impp (STC)	12,81 A – 17,33 A
Open-Circuit Voltage (STC)	37,5 V – 49,9 V
Short-Circuit Current (STC)	13,75 A – 18,41 A
Module capacity (NOCT**)	400,9 Wp – 409 Wp
Voltage Vmpp (NOCT)	29 V – 39,7 V
Current Impp (NOCT)	10,25 A – 14,1 A
Open-Circuit Voltage (NOCT)	35,14 V – 47,4 V
Short-Circuit Current (NOCT)	10,86 A – 14,91 A
Max. module voltage	1500 V DC
Module efficiency ≥ 20%	≥ 20,65%
Technology	Half-cell
Temperature coefficient at Pmax	≥ -0.36 %/K
Cell efficiency after 25 years	≥ 83.1%
Minimum glass thickness	3.2mm
Thickness of Anodised Aluminium Frame	35mm
Module weight	≤ 29 kg
Snow load	≥ 5 400 Pa
Wind load	≥ 2 400 Pa
Operating temperature	-40 do + 85°C
Cable length	≥ 1 000 mm
Minimum IP protection of a distribution box	IP 67
Minimum guarantee for the product	12 years
Minimum guarantee for cell efficiency	25 years
Additional protection	Anti PID (Potential Induced Degradation)
Standards	IEC 61215-1-1:2021 ED2, IEC 61730-1:2019, IEC 61701:2020 ED3, IEC 62716:2013/COR1:2014 ED1, G59/3

*STS (Standard test conditions) – standard test conditions: PV panel is clean, no dust or other filth which are possible in real conditions, irradiation 1000 W/m², 25°C cell temperature, AM 1.5, all parameters comply with MEST EN 60904-3
**NOCT (Normal operating cell temperature) – cell temperatures under the following conditions: irradiation 800 W/m², wind speed 1m/s, 20°C ambient temperature

Prior to the beginning of the project implementation, it is necessary to consider and create the mechanism to check efficiency of PV cells during exploitation term and ensure maximum protection of beneficiaries. Elaborate analyses can be conducted in the professional laboratory which tests technical features of PV modules, which must be organized on a national level, in accordance with recommendations and standards governing this area.

3.3 Inverter – required technical features

Invertors performing DC/AC transformation must be 3-phase inverters, without transformer and with the efficiency of ≥98%. These are grid-controlled devices which cannot operate in an island mode, i.e. they are unable to function in case of loss of supply from the distribution grid and loss of synchronism. Inverters must be equipped with minimum two MPPT devices so as to implement parallel connection of PV modules installed on two rooftops with various inclined angles and in various orientations. Flexibility of implementing the technical solution will be increased in this way.

Inverter with the capacity of 100 kW can be equipped with only one MPPT device, having in mind that use of this inverter is envisaged for major systems with substantial rooftops which have the same orientation and tilt.

Output inverters must provide clean sinusoid with minimum grouting of a one-way component of the current and the higher harmonics current in the distribution grid. These energy electronics devices must be certified so as to guarantee compliance with technical requirements set out in G59/3, issued by Energy Networks Association (ENA). Furthermore, it is very important for the inverters to be compliant with MEST EN 61000-3-2 and MEST EN 61000-3-12 which set out limit values for harmonic current emissions. The total harmonic distortions must be <3%.

The inverter must have 0.8-1 ind./cap., i.e. it should have the possibility of grouting or absorbing reactive power or limiting supply of active energy in order to maintain stable voltage conditions.

In addition to the above mentioned characteristics, the inverter must be able to limit the power concerning prohibited supply of electricity to the distribution grid, providing such requirements are made in the future by the distribution system operator.

The inverter must have the following integrated protection types:

- Protection against island mode operation
- Measurement of DC insulation and the protection should the insulation be broken
- RPP (reverse polarity protection)
- RCMU (Residual current monitoring unit)
- Integrated DC SPD, type 1+2, for each MPPT individually
- Integrated DC fusible plug 10x38 with rated power 20A

Technical features of the inverter planned to be installed:

Grid-controlled inverter	10 kW rated power inverter	20 kW rated power inverter	50 kW rated power inverter	100 kW rated power inverter
Input parameters:				
Input DC inverter power	≥ 11 kWp	≥ 24 kWp	≥ 52 kWp	≥ 110 kWp
No. of MPPT devices	2	2	1	1
Minimum no. of DC connections per MPPT device	1	2	2	2
Minimum input voltage range	250 - 850 V DC	230 - 950 V DC	580 - 700 V DC	705 - 850 V DC
Output parameters:				
Inverter output power	10 kW	20 kW	50 kW	100 kW

Grid voltage	3-NPE 400/230V			
Frequency	50/60 Hz			
Power factor	0 - 1 ind./cap.	0 - 1 ind./cap.	0 - 1 ind./cap.	0 - 1 ind./cap.
General features:				
IP protection	IP 65			
Operating temperature range	-20 do +60°C			
Maximum efficiency	≥ 97,2%	≥ 98,1%	≥ 98,1%	≥ 98,4%
Protection:				
Protection against island mode operation	Integrated			
Reverse polarity protection	Integrated			
DC switch-disconnector	Integrated			
DC fusible plugs 20 A (4 pieces)	Integrated			
RCMU Protection	Integrated			
It is necessary to ensure certificate to confirm compliance with differential switch – Type A				
DC SPD, Type 1+2, for each MPPT device, in compliance with IEC 61643-31	Integrated			
Communication:				
Ethernet and WLAN interface	YES			
Data logger for data collection and acquisition	Integrated			
RS485 communication with smart meter	Integrated			
Energy management in real time, smartphone and PC application	Integrated			
IO module (min. 4 digital inputs and 4 digital outputs)	Integrated			
Standards IEC 62109-3:2020 ED1; IEC 62116:2014 ED2; IEC 61727:2004 ED2, MEST EN 61000-3-2:2016, MEST EN 50438:2013; MEST EN 50549-1:2021; MEST EN 60255				

Inverters are made in IP65 protection, which enables their installation on facades of facilities or inside of them, in technical or some other premises. In case of installation thereof outside of the structure, inverters must be additionally protected against direct solar irradiance which can have a negative impact on the lifetime of energy electronics.

Communication between the inverter and smart meter is established by installing SFTP CAT 6 communication cable, whereas these devices perform exchange of data about technical parameters in real time. Data logger performs data collection and acquisition; it is located inside the inverter. In order for all these data to be available to the beneficiary, the inverter should be connected to the Internet and the web server. Connection should be performed using wires, via Ethernet cable or over the air, via WiFi. While visiting the facility, it is necessary to define the possibility of connecting the system to the Internet - WiFi should be used for data exchange only in special situations, when communication can not be established through wires. In such cases, the responsible engineer is obliged to prepare a report containing explanation why it is not possible to establish communication through wires with the local network.
The system for monitoring technical and economic parameters will be described in a separate chapter.

The typical guarantee for the inverter is 5 years, given that the manufacturers of inverters offer the possibility to purchase the guarantee package of up to 20 years. **It is proposed to extend the package to 8 or 10 years (which will be set out in tender documents) until expiry of EPCG's contract signed with beneficiaries.**

According to the applicable technical recommendations of the distribution system operator, inverters must meet the following standards:

- MEST EN 50549-1:2021
- MEST EN 62109
- MEST EN 60255
- MEST EN 61000
- MEST EN 62116
- MEST EN 60255-6
-

Having in mind major capacities of the system, inverters should contain integrated V/W and V/VAr control although distribution sources are not responsible for the control of technical parameters of the power system, according to legal regulations. The possibility of a future systemic effect onto electricity quality in the low-voltage distribution grid has been envisaged in this way, as well as increase of a reliable system operation.

Below tables present voltage values used by the inverter to automatically regulate output power:

	Voltage	Active power percentage (% of rated power)
U1	207 V	100 %
U2	220 V	100 %
U3	250 V	100 %
U4	258 V	20 %

	Voltage	Reactive power percentage (% of rated power)
U1	207 V	30% inductive
U2	220 V	0 %
U3	250 V	0 %
U4	258 V	30 % capacitive

The values are set out in line with MEST EN 50549-1. All settings are made by certified entities, trained to deal with power electronics devices. Modification of set parameters is strictly prohibited.

This technical solution does not envisage analysis of the impact of 70 MW PV systems connection to the distribution grid. Therefore, it is necessary to prepare a separate study with a focus on this technical challenge.

3.4 EXPECTED RESULTS OF SOLAR 5000+ PROJECT

Using the aforementioned parameters and assessments, the following results are obtained:

- Total installed capacity of distributed PV systems amounts to **70 MW (81 MWp)**
- Envisaged annual electricity generation amounts to **109,35 GWh**
- Average value of specific annual electricity yield smounts to **1 350 kWh/kWp**

3.5 Recommendations for configuration of PV systems

Configuration of PV system must be carried out in compliance with certain rules which ensure the optimum and efficient functioning of the system with maximum electricity yield. Good design practice recommends so-called “overpaneling” - DC system power should be up to 20% higher than AC power so that efficiency of installed equipment would be increased. Rated power of 540 Wp PV module is defined in STC conditions which are unachievable in reality; maximum system capacity which can be achieved at the output of an inverter (AC) amounts to about 85% of the total rated DC power of the system.

A string is a series of connected PV modules which are connected directly to the inverter device. Total string voltage obtained by summing voltages of all individual modules in the series, must be within allowed range of input DC voltage inverters. Maximum string voltage is expected at low temperatures, so it is necessary to perform a technical check whether all required technical parameters are fulfilled. Strings with the same number of PV modules, which have the same orientation and the same tilt angle, can be connected in paraller to the same MPPT.

Shading a part of one module in the string results in significant power reduction of that string. Because of this phenomenon, it is necessary to consider vertical and horizontal connection of modules so that the shaded string would be isolated and shading impact on the total electricity generation would be reduced.

When forming strings, it is necessary to run + and - DC cables directly next to each other in order to reduce the electromagnetic field between the poles and reduce the possibility of direct atmospheric discharges. Atmospheric discharges protection is carried out through placing a surge arrester to AC and DC side of the PV system. Cables ought to be properly placed on the cable rack system.

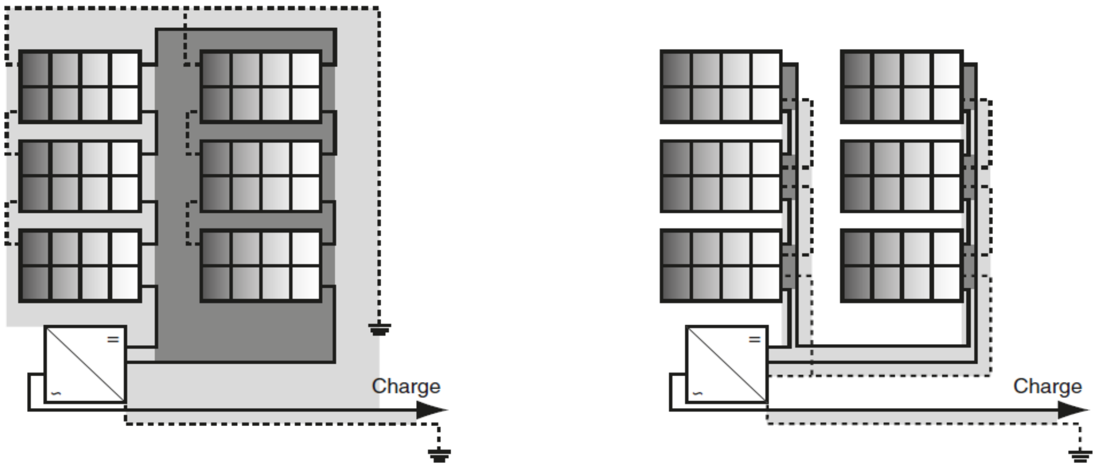

Figure 2: *Reduction of electromagnetic field between positive and negative poles of DC system (source: Electrical installation Guide 2018 - Schneider Electric)*

3.6 System for monitoring of technical and economic parameters

Every photovoltaic system has to have a system for technical and economic parameters monitoring.

There are two basic and most important functions of this system:
1. Real-time monitoring of the power plant operation, analysis of historical data on facility consumption and photovoltaic system production, analysis of economic return on investment, CO2 reduction
2. Alarming users and the maintenance service in case of a system failure

The monitoring system is easily established by connecting the inverter and smart meter (smart meter must be compatible with inverter device) to the manufacturer's web platform. The platform has to be easy for use and free of charge, without any monthly fees that would additionally burden the investment.

Technical parameters that need to be analyzed are the following:
- Delivered and taken over electricity
- AC and DC voltages for each phase at the connection point and on the inverter
- AC and DC currents on the inverter
- Active and reactive power
- Power factor

In addition to the technical parameters that need to be analyzed in real time, the monitoring system has to calculate and display financial savings based on predefined input data as well as savings in CO2 emissions through electricity generation from a green source.

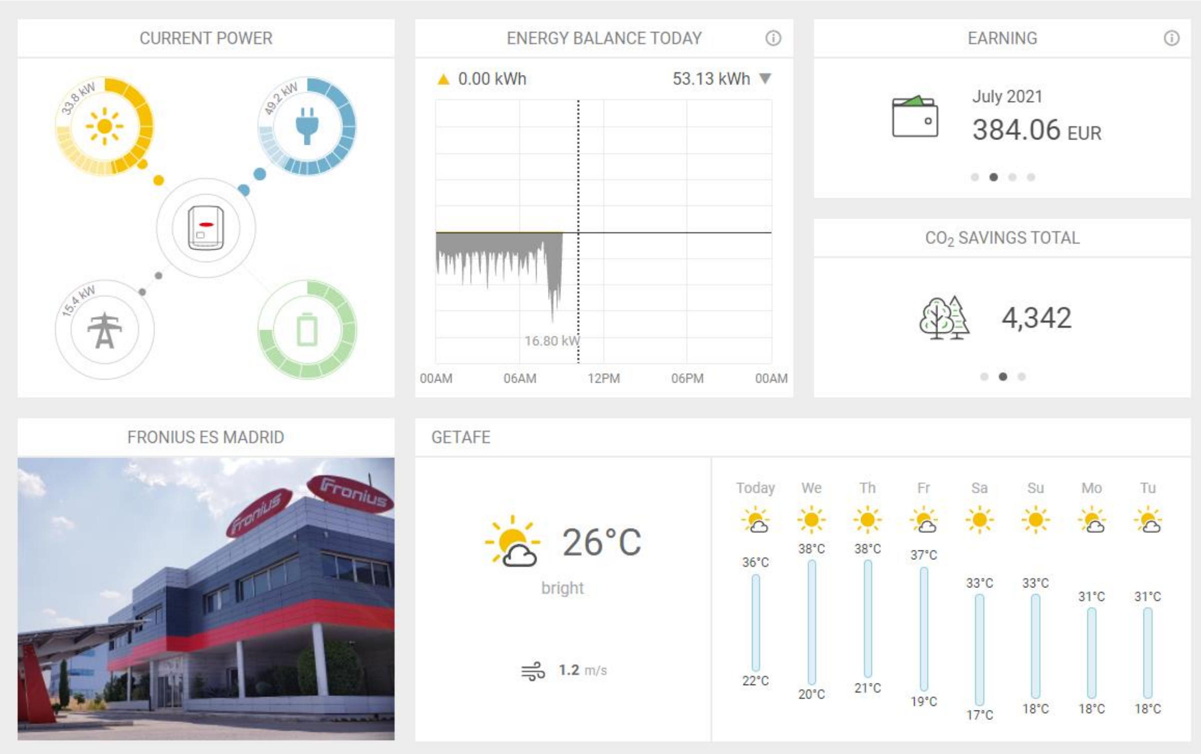

Figure 3: *Overview of the platform for technical and economic parameters monitoring of the system*

After the installation of the system, it is necessary to train the users and inform them about the possibilities of analyzing the data on the system operation.

The inverter supplier is obliged to provide the possibility of a remote monitoring and control of the inverter via the Internet network and assign to EPCG the status of an administrator, whereby each user would have the possibility of monitoring the parameters of their own system.

3.7 Energy equipment for connection of a photovoltaic system

Having in mind an extensive range of photovoltaic system capacities as well as conditions under which this project is planned to be implemented, it is not possible to uniform the technical solution to create detailed technical specification of the equipment for connection of photovoltaic systems - distribution cabinets including protective energy equipment and cable infrastructure. Creation of the model of cooperation with companies supplying this equipment has therefore been proposed so that, within short time period and immediately upon completion of the Main Design and preparation of the detailed technical specification, equipment could be procured and supplied. In order to optimize the process, it is possible to identify certain types of circuit breakers, disconnectors, cables, distribution cabinets and other elements for the suppliers to prepare and secure storage of the equipment.

3.8 Substructure

The design defines the use of prefabricated aluminum elements for mounting of photovoltaic modules on a roof. Aluminum alloy can be 6005T6, AW-6063 T66 or AI6061-T6. Prefabricated elements must have ISO 9001, compliant with Eurocode 9. The two substructure systems are included in the design - the first system is intended for fixing of a module on a roof made of trapezoidal sheet metal - sandwich panel (70%), and the second system for installation of a module on a flat concrete roof (30%), without drilling the existing concrete structure, using concrete ballast as weights for fastening aluminium structure. The supports and rails of the substructure are made of aluminum (aluminum alloys EN AW-6063 or EN AW-6005) while the connecting and fastening elements are made of a stainless steel (1.4301 or 1.4307). The connecting elements of the system have to correspond to the 35mm thickness of the module frame. Potential equalization between the module frame and the aluminum substructure is done using prefabricated elements. In addition, it is necessary to establish a strong galvanic connection between the substructure and the receiving system, depending on whether the distance criteria between metal masses and and receiving system of the lightning protection installation are adequately satisfied.

When it comes to a roof made of, the support is screwed directly to sheet metal ribs, in the manner defined in technical instructions for installation provided by the manufacturer of a substructure system. This type of trapezoidal sheet metal support is mainly produced in form of short rails. The manufacturer of substructure elements is obliged to guarantee that the waterproofing of the roof will not be endangered while drilling the sheet metal. Photovoltaic module is directly mounted on the support and it is fastened with adequate mid or end clamps.
Some of the substructure elements for trapezoidal sheet metal (10% of the total quantity of a substructure for trapezoidal sheet metal) must include aluminium rails 6m long so as to bypass skylights or other similar parts of a roof.

The details of the installation of the photovoltaic module on trapezoidal sheet metal roof (sandwich panel) have to be defined by the Main Design of a photovoltaic system, for each facility independently.

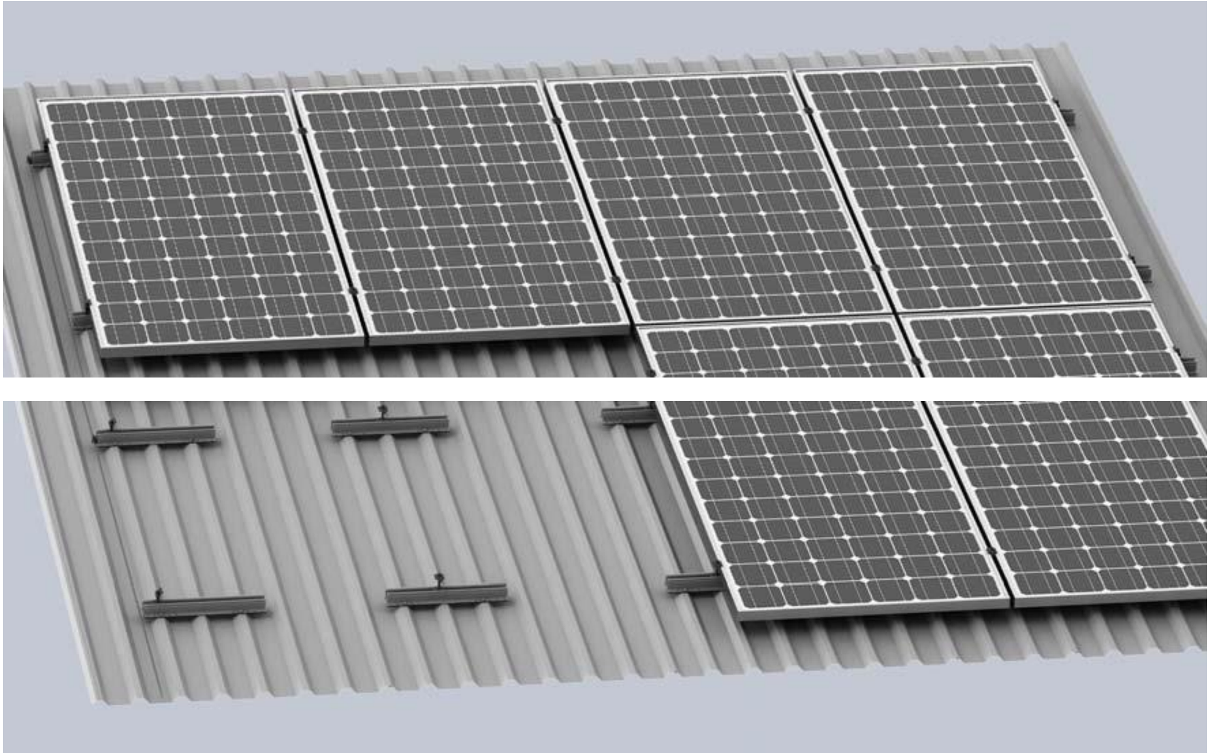

Figure 4: *Detail of placing the support on the roof made of trapezoidal sheet metal*

Photovoltaic modules on roofs made of trapezoidal sheet metal should be placed into a “portait” position so as to optimize utilization of the substructure system.

Mounting the module on a flat concrete roof is performed by using adequate aluminum substructures, whereby this substructure regulates tilt of the module. It is recommended that the minimum tilt angle for module installation be 10°. The flat concrete panel is not drilled; however, fastening of substructure elements made of aluminum or aluminium alloys is performed using concrete ballasts. While developing the Study on the impact of a photovoltaic system on the facility statics (this Study represents an integral part of project documents) it is necessary to calculate load depending on the location and prepare the plan of installation of concrete ballasts.

The Main Design should define the technical solution which, in most cases, is going to be divided into two concepts:

- Southward orientation of the module given that the space between the two rows (front and back) is envisaged to avoid shading of the module’s back row. This solution has been assessed as most efficient, generating maximum electricity output per module installed.
- East-west configuration according to which one part of a module is east-oriented and another part west-oriented. This solution is less efficient compared to southward orientation; however, it provides certain benefits such as better expoitation of the available roof area as well as higher resistance to system mobility due to strong gusts of wind what directly reduces necessary quantity of concrete ballasts which should be provided in order to preserve static charasteristics of the system.

Figure 5: *Detail demontrating placement of concrete ballasts on aluminum substructure – southward orientation of photovoltaic modules*

Photovoltaic modules on flat concrete roofs should be installed in a "landscape" orientation so as to optimize utilization of the available space.

3.9 Lightning protection installation

SOLAR 5,000+ project plans to equip the facilities owned by legal entities assuming that majority of such facilities has the lightning protection installed. Depending on a roof surface type (roof made of trapezoidal sheet metal or flat concrete roof), it is necessary to envisage additional measures of protecting photovoltaic system elements via earthing of metal masses.

According to technical recommendations, three cases are analysed herein, those that can be implemented in practice.

<u>SCENARIO 1:</u> FACILITY HAS NO LIGHTNING PROTECTION INSTALLATION

If the facility has no lightning protection installed, it is not necessary to construct new lightning protection installation because it has not been proven that installation of photovoltaic modules could increase the possibility of a direct atmospheric discharge. In this particular case, the protection needed is type 2 SPD for DC and AC side, while metal masses of a photovoltaic system should be galvanic connected to the earthing system of the facility by installing copper protective P/F conductor of a minimum 6 mm^2 cross-section.

<u>SCENARIO 2</u>: THE FACILITY HAS LIGHTNING PROTECTION INSTALLED AND IT IS POSSIBLE TO ENSURE DISTANCE S

In this case, it is very important to identify the condition of the existing lightning protection and whether it is possible to install photovoltaic system in a way which would ensure adequate separation distance S at all positions. This is a distance between parts of the receiving system of a lightning protection installation and metal masses of photovoltaic equipment, and it is important to satisfy it so that dangerous excess voltage on metal masses of a photovoltaic system would not be induced, which could damage the equipment and endanger safety. Protective zone of the existing lightning protection installation can be defined by the “rolling ball” method.

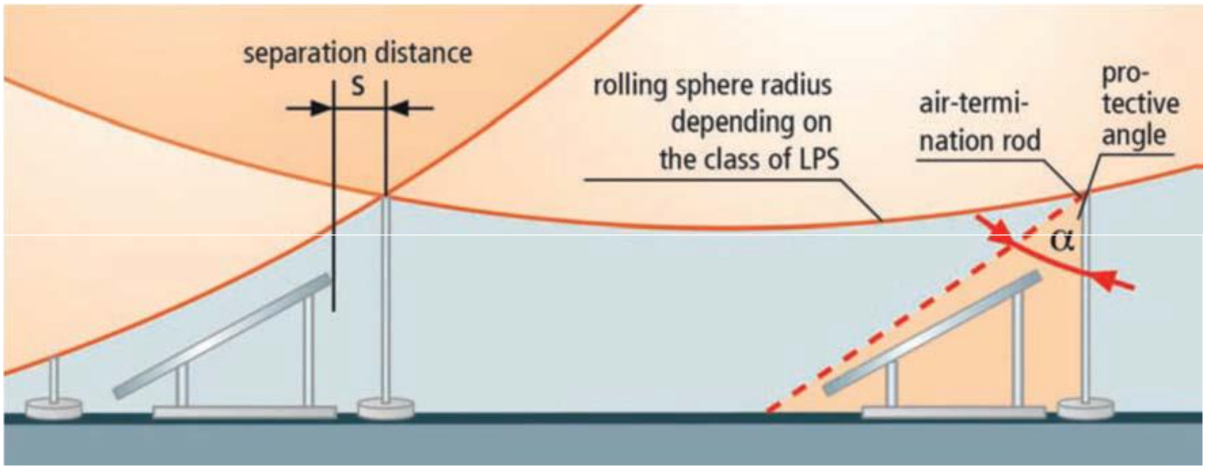

Figure 5: *Determination of the protective zone of lightning protection installation using “rolling ball” method (source: Earthing and lightning overvoltage protection for PV plant)*

In this case, as a protection measure, it is necessary to apply Type 1 SPD on AC side while Type 2 SPDs on DC side are enough to be used. In case the distance between the ineverter and the point of connection to the distribution grid exceeds 10 m, Type 2 SPD should be additionally placed on AC side, as close to the inverter device as possible. As stated above, metal masses in this case should be connected to the earthing system using P/F copper conductor of a minimum 6 mm^2 cross-section.

<u>SCENARIO 3: THE FACILITY POSSESSES THE LIGHTNING PROTECTION INSTALLATION AND IT IS NOT POSSIBLE TO ENSURE DISTANCES</u>

If the facility possesses the lighting protection installation and due to small rooftop area it is not possible to ensure separation distance S, then the metal masses of photovoltaic system are galvanically connected with receiving system of the lighting protection installation taking care of the application of additional protection measures against overvoltage. Cross-section of the conductor with which earthing of metal masses and connecting with lighting protection installation is carried out must not be lower than 16 mm2. Each MPPT of inverter must be equipped with SPD Type 1+2, while surge arrestor Type 1+2 is also recommended on AC side. If the connection point is at the distance of more than 10m from the inverter position, then surge arrestor Type 1 is necessary to be installed also at the point of the plant connection to the distribution network.

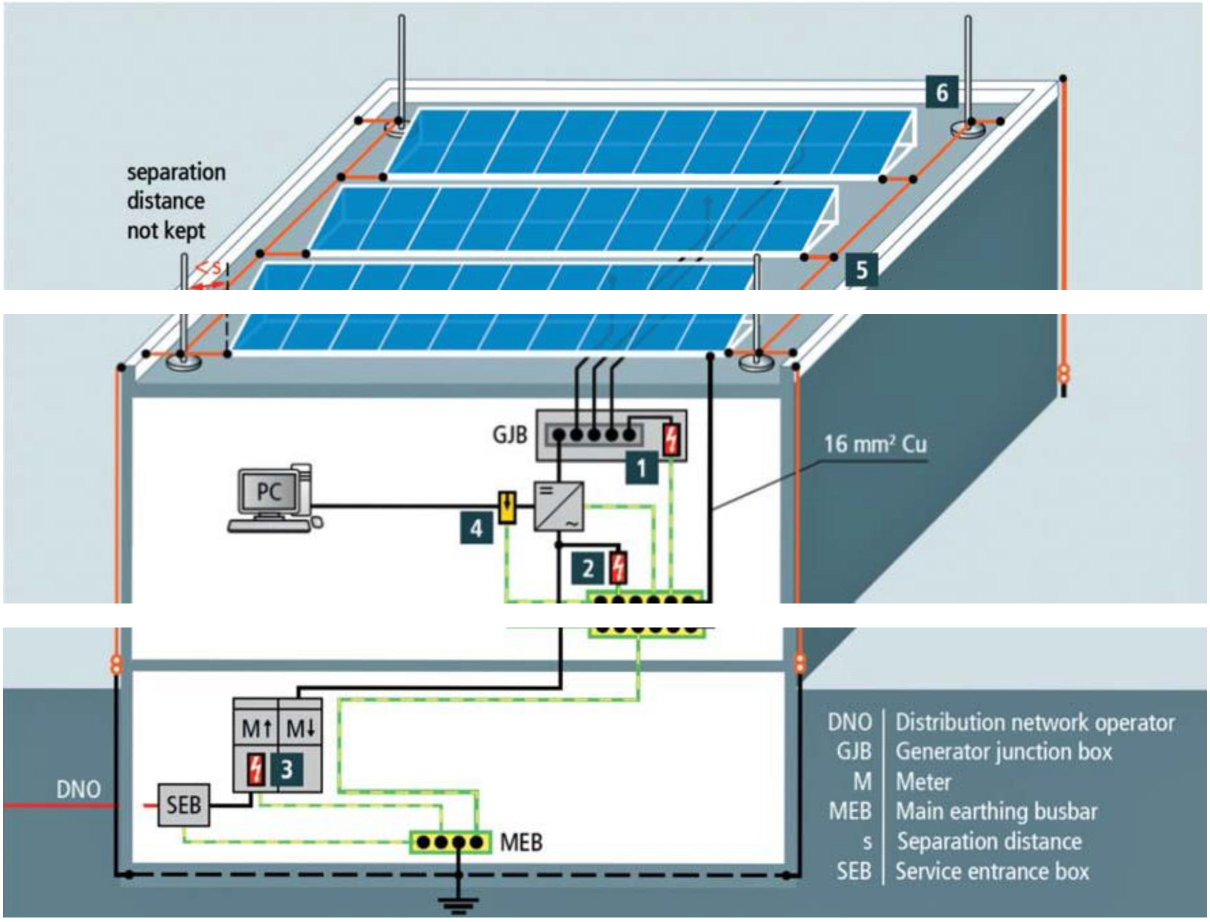

Figure 7: Presentation of the facility with lightning protection installation where separation distance S is not possible to be ensured (source: Earthing and lightning overvoltage protection for PV plant)

Metal masses of photovoltaic system are necessary to be connected with copper P/F conductor with the cross-section of 16 mm^2 with protective busbars in the cabinet which is planned to be installed in the immediate vicinity of the inverter.

Engineer in charge:

Lazar Komar, ma.el.eng

4. PRICED BILL OF QUANTITIES

PRICED BILL OF QUANTITIES
SOLARI 5000+ PROJECT

Facility: Photovoltaic systems (SOLARI 5000+ PROJECT)
Investor: Elektroprivreda Crne Gore
Location: Montenegro
Designer: Greener d.o.o.
Type of technical documents: Preliminary Technical design
Part of technical documents: Electrical-technical design - PV system
Date: November 2022

No.	***Item description***	***Unit of measure***	***Quantity***	***Unit price***	***Total:***

1 PHOTOVOLTAIC SYSTEM

1.1. Procurement, transport, delivery and assembly of monocristaline PV panels with following characteristics:
Module capacity (STC) **540 Wp**
Current Impp (STC) **12,81 A – 17,33 A**
Voltage Vmpp (STC) **31,2 V – 42,15 V**
Open circuit voltage (STC) **37,5 V – 49,9 V**
Short-circuit current (STC) **13,75 A – 18,41 A**
Module capacity (NOCT) **≥ 400,9 W**
Voltage Vmpp (NOCT) **29 V – 39,7 V**
Current Impp (NOCT) **10,25 A – 14,1 A**
Open circuit voltage (NOCT) **35,14 V – 47,4 V**
Short-circuit current (NOCT) **10,86 A – 14,91 A**
Maximum module voltage **1500 V DC**
Module efficiency **≥ 20,65 %**
Half cell technology
Temperature coefficient at Pmax **≥ -0.36 %/K**
Cell efficiency after 25 years **≥ 84.8%**
Minimum glass thickness **3.2mm**

Anodized aluminum frame with maximum thickness **35mm**

Module weight **≤ 29 kg**

Snow load **≥ 5 400 Pa**

Wind load **≥ 2 400 Pa**

Operating temperature **-40 do + 85°C**

Minimum IP protection of control box **IP 67**

Minimum product guarantee **12 years**

Minimum guarantee for cell efficiency **25 years**

Anti PID (potential induced degradation) protection

Standards IEC 61215-1-1:2021 ED2, IEC 61730-1:2019,
IEC 61701:2020 ED3, IEC 62716:2013/COR1:2014 ED1, G59/3

Total PV modules **26.700.000,00 €**

2 Inverters

2.1. Grid-controlled inverter with rated power of 10 kW and the following technical characteristics:

Input parameters:

Input DC power of inverter ≥ 12 kWp

Number of MPPT devices 2

Minimum number of DC connections per MPPT device 1

Minimum range of input voltage 200 - 850 V DC

Output parameters:

Output power of inverter 10 kW

Network voltage 3-NPE 400/230V

Frequency 50 Hz

Capacity factor 0.8 - 1 ind./cap.

THD < 3%

General characteristics:

Maximum weight 41 kg

Protection IP 65

Operating temperature range -25 to +60°C

Maximum efficiency ≥ 97%

Protections:

Integrated anti-islanding protection

Integrated reverse polarity protection

DC disconnector

Integrated RCMU (residual current monitoring unit) protection

It is necessary to ensure a certificate that attests compatibility with the differential switch –type A

Integrated DC surge arrester type 2, for each MPPT device in line with IEC 61643-31 standard

Regulation V/W and V/VAr (default regulation should be switched off with possibility to switch on if needed)

Communication:

Ethernet and WLAN interface

Integrated data logger for data collection and acquisition

RS485 communication with the smart meter

Real time energy management, smartphone and PC application

It is necessary to envisage a possibility to redefine, subsequently,
technical parameters of integrated protections of inverters
in line with current legislation

TOTAL: pcs. 500 1640 820.000,00 €

2.2. Grid-controlled inverter with rated power of 20 kW and the following technical characteristics:

Input parameters:

Input DC power of inverter ≥ 24 kWp

Number of MPPT devices 2

Minimum number of DC connections per MPPT device 2

Minimum range of input voltage 200 - 850 V DC

Output parameters:

Output power of inverter 20 kW

Network voltage 3-NPE 400/230V

Frequency 50 Hz

Capacity factor 0 - 1 ind./cap.

General characteristics:

Protection IP 65

Operating temperature range -25 to +60°C Maximum efficiency ≥ 97%

Protections:

Integrated anti-islanding protection

Integrated reverse polarity protection

DC disconnector

Integrated RCMU (residual current monitoring unit) protection

It is necessary to ensure a certificate that attests compatibility with the differential switch –type A

Integrated DC surge arrester type 2, for each MPPT device
in line with IEC 61643-31 standard

Integrated DC fusible plug 10x38 rated currency 20A (4 pcs.)

Regulation V/W and V/VAr (default regulation should be switched off with possibility to switch on if needed)

Communication:

Ethernet and WLAN interface

Integrated data logger for data collection and acquisition

RS485 communication with the smart meter

Real time energy management, smartphone and PC application

It is necessary to envisage a possibility to redefine, subsequently, technical parameters of integrated protections of inverters in line with current legislation

TOTAL: pcs. 800 2045,0 1.636.000,00 €

2.3. Grid-controlled inverter with rated power of 50 kW and the following technical characteristics:

Input parameters:

Input DC power of inverter ≥ 60 kWp

Number of MPPT devices 2

Minimum number of DC connections per MPPT device 2

Minimum range of input voltage 200 - 850 V DC

Output parameters:

Output power of inverter 50 kW

Network voltage 3-NPE 400/230V

Frequency 50 Hz

Capacity factor 0 - 1 ind./cap.

THD <3%

General characteristics:

Protection IP 65

Operating temperature range -25 to +60°C

Maximum efficiency ≥ 97%

Protections:

Integrated anti-islanding protection

Integrated reverse polarity protection

DC disconnector

Integrated RCMU (residual current monitoring unit) protection

Integrated DC surge arrester type 2, for each MPPT device in line with IEC 61643-31 standard

Integrated DC fusible plug 10x38 rated currency 20A (4 pcs.)

Regulation V/W and V/VAr (default regulation should be switched off with possibility to switch on if needed)

Communication:

Ethernet and WLAN interface

Integrated data logger for data collection and acquisition

RS485 communication with the smart meter

Real time energy management, smartphone and PC application

It is necessary to envisage a possibility to redefine, subsequently, technical parameters of integrated protections of inverters in line with current legislation

TOTAL:	pcs.	280	3750,0	1.050.000,00€

2.4. Grid-controlled inverter with rated power of 100 kW and the following technical characteristics:

Input parameters:

Input DC power of inverter ≥ 120 kWp

Number of MPPT devices 1

Minimum number of DC connections per MPPT device 2

Minimum range of input voltage 200 - 850 V DC

Output parameters:

Output power of inverter 100 kW

Network voltage 3-NPE 400/230V

Frequency 50 Hz

Capacity factor 0 - 1 ind./cap.

THD <3%

General characteristics:

Protection IP 65

Operating temperature range -25 to +60°C

Maximum efficiency ≥ 97%

Protections:

Integrated anti-islanding protection

Integrated reverse polarity protection

DC disconnector

Integrated RCMU (residual current monitoring unit) protection

Integrated DC surge arrester type 2, for each MPPT device in line with IEC 61643-31 standard

Integrated DC fusible plug 10x38 rated currency 20A (4 pcs.)

Regulation V/W and V/VAr (default regulation should be switched off with possibility to switch on if needed)

Communication:

Ethernet and WLAN interface

Integrated data logger for data collection and acquisition

RS485 communication with the smart meter

Real time energy management, smartphone and PC application

It is necessary to envisage a possibility to redefine, subsequently, technical parameters of integrated protections of inverters in line with current legislation

TOTAL:	pcs.	350	4950,0	1.732.500,00€

2.5. Procurement, transport, delivery and installation of smart meter devices for communication and electricity exchange monitoring. Measurement is being done indirectly, by X/5A current transformers precision class 0.5. Rated voltage range from 400-480V (l-L) / 230-277V (P-N), max current of secondary is 6A. Assembly of meter is done on DIN rail.

	pcs.	1250	220,0	275.000,00€

Total inverters: **5.513.500,00 €**

3 SUB-STRUCTURE

Roof made of a trapezoidal metal sheet (sandwich panel)

3.1.	Procurement of aluminum substructure elements for PVs fastening to the rooftop surface made of trapezoidal metal sheet (sandwich panel). Substructure system consists of short aluminum rails (module carrier), end and medium clamps, like Minirail type, of K2 manufacturer, Germany.	set	1	1.380.000,0	1.380.000,00€
3.2.	Procurement of aluminum substructure elements for PVs fastening to the rooftop surface, made of trapezoidal metal sheet (sandwich panel). Substructure system consists of short aluminum 6m wide rails (module carrier), end and medium clamps, like Speedrail type, of K2 manufacturer, Germany.	set	1	360.000,00	360.000,00€
3.3.	Procurement of substructure elements, made of aluminum, for PV modules fastening to the rooftop surface, made of trapezoidal metal sheet (sandwich panel), with increase in a module erection tilt by 10 degrees. Substructure system consists of: short rails Multirail alike, of K2 manufacturer, front and rear carrier with module lifting by 10 degrees, clamps for module fastening. The system resembles the S dome small type, manufactured by K2 System, Germany.	set	1	395.000,00	395.000,00€
Flat concrete roof					
3.4.	Procurement of substructure aluminum elements for PV modules fastening to flat roof. Modules are south oriented with a tilt of 10 degree. System elements are the following: upper and lower carrier for modules fixing with a tilt of 10 degrees, petty assembly material, windshield, end and mid-clamps, rails for modules assembly, ballast kit, supporting element for protection of the roof membrane. *Note: Concrete ballasts have not been calculated in the price of the system*.	set	1	1.450.000,00	
3.5.	Procurement of substructure aluminum elements for PV modules fastening to flat roof in east-to-west configuration. Modules are east to west oriented with a tilt of 10 degree. System elements are the following: upper and lower carrier for modules fixing with a tilt of 10 degrees, petty assembly material, windshield, end and mid-clamps, rails for modules assembly, ballast kit, supporting element for protection of the roof membrane. *Note: Concrete ballasts have not been calculated in the price of the system.*	set	1	880.000,00	880.000,00€
	TOTAL – SUBSTRUCTURE				**4.465.000,00€**

4. POWER COUPLING EQUIPMENT (12.5% of investment)

4.1.	Procurement of distribution cubicles equipped with energy protection equipment, DC and AC cables of suitable cross section, communication cables, cable racks system, MC4 connectors, relays and other equipment necessary for connection of a PV system.	set	1	8750000,0	8.750.000,00€
	Total, calculated for electrical fitting works:				**8.750.000,00€**

5	**ELECTRICAL FITTING WORKS (15% investment)**				
5.1	Electrical Fitting works implying assembly of PV modules and substructures, coupling of strings to inverters, placement of protection cubicles, connection of feeding cables and connection of a system to a distribution network.	set	1	10500000,0	10.500.000,00 €
	TOTAL – ELECTRICAL FITTING WORKS				**10.500.000,00 €**

6.	**REMAINING ADMINISTRATIVE COSTS (3% of investment)**				
6.1.	Administrative costs	set	1	2100000,0	2.100.000,00€
	Total for testing:				**2.100.000,00 €**

OVERVIEW

1	**Photovoltaic modules**	**26.700.000,00 €**
2	**Inverters**	**5.513.500,00 €**
3	**Substructure**	**4.465.000,00 €**
4	**Power coupling equipment**	**8.750.000,00 €**
5	**Electrical fitting works**	**10.500.000,00 €**
6	**Remaining administrative costs**	**2.100.000,00 €**
	TOTAL, without VAT:	**58.028.500,00 €**
	VAT (21%)	**12.185.985,00 €**
	TOTAL, VAT included	**70.214.485,00 €**

Responsible engineer:

Lazar Komar, M.Sc. Eng.