PSS FOR ELECTRICAL ENERGY PRODUCTION FROM SOLAR RADIATION ON THE ROOF OF THE EXISTING BUILDING "APM PRINT"

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Summary: *The main design includes constructing the facility for electrical energy production – network photovoltaic system (NPS) on the existing building with 60kW of the installed power.It is also planned to install solar panels manufactured by Sharp, 270W type. The dimensions of a solar panel are 1650x992x45mm and the weight is 19.0kg. Solar panels are mounted on a standard light aluminium structure of ALUMIL SOLAR MOUNTING SYSTEM AS405 type, manufactured by ALUMIL SOLAR, intended for the installation onto the industrial panels.*

Keywords: *photovoltaic system, electrical energy, network photovoltaic system (NPS)*

1. INTRODUCTION

The location for electrical energy production by using the network photovoltaic system (NPS) is on the roof of the existing building – the printing house "APM Print", 29 Milutin Milanković Boulevard, New Belgrade. For the needs of the investor, it is required to create Main electrical design of the network photovoltaic system for electrical energy production by using solar radiation on the roof of the existing building – NPS with 60kW of the installed power, with all accompanying facilities.

Image 1. Location plan of the building "APM Print", 29 Milutin Milanković Boulevard, New Belgrade

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The Main electrical design of the facility for electrical energy production should be created in accordance with:

- The Law on Planning and Construction (”Službeni glasnik“ No. 72/2009)
- The Law on Fire Protection (”Službeni glasnik“ No. 111/2009)
- Technical regulations and laws on preparation of technical documentation, in accordance with the legislative regulations of the Republic of Serbia.

The purpose of the facility is to generate electrical energy out of the solar energy by using a solar field with photovoltaic panels. The design includes that the above-mentioned system generates electrical energy and directs the entire production into the network. The designed facility is mounted on the roof of the existing building structure – the printing house in New Belgrade, image 1.

2. TECHNICAL SOLUTION – SOLAR FIELD

The main design includes constructing the facility for electrical energy production – network photovoltaic system (NPS) on the existing building with 60kW of the installed power. It is also planned to install solar panels manufactured by Sharp, 270W type. The dimensions of a solar panel are 1650x992x45mm and the weight is 19.0kg. Solar panels are mounted on a standard light aluminium structure of ALUMIL SOLAR MOUNTING SYSTEM AS405 type, manufactured by ALUMIL SOLAR, intended for the installation onto the industrial panels. Panel holders are screwed into the existing roof structure, which is shown in the image 2. Mounting of the substructure supports on the roof structure is shown in the image 3.

Figure 2. Panel holders screwed into the roof structure of the printing house ”APM Print“, New Belgrade

Image 3. Mounting of the substructure supports onto the roof structure (L_1=0.8m)

Specially designed profiles are connected with holders and they function as solar panel girders. The panels are placed into the space between top and bottom horizontal rails. Polycrystalline photovoltaic panels, manufactured by Sharp, 270Wp, are planned for the construction of a photovoltaic solar field. Basic technical characteristics of these panels are shown in the table 1, based on the data provided from the manufacturers.

Table 1. Characteristics of the photovoltaic panels for the construction of a solar field

Solar cell type	Polycrystalline silicon cell 156x156mm
Number of cells on a panel	60 (6x10)
Panel dimensions	1650x992x45mm
Panel weight	19 kg
Panel glass	Safety tempered glass, 3.2mm of width
Panel frame	Anodized aluminium
Energy tolerance	+/-3%
Ambient temperature	From -40°C to +85°C
Service cable length	800mm
Guaranteed efficiency	90% for 10 years/ 80% for 25 years
Warranty	10 years

Photovoltaic panels for electrical energy production are set on the light aluminium prefabricated structure of AS-405 type, manufactured by ALUMIL SOLAR, which is mounted on the roof of the existing building (image 4).

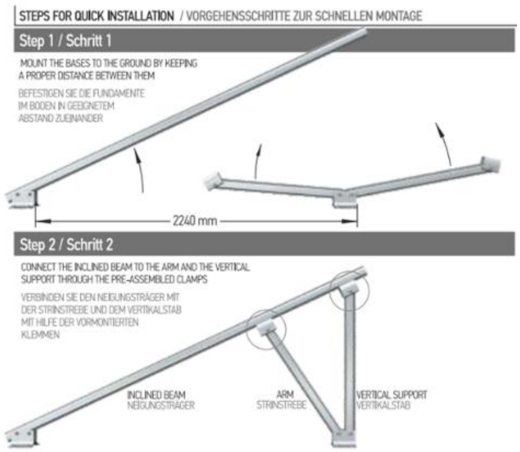

Image 4. Photovoltaic panels for electrical energy production

Photovoltaic panels are set in the portrait orientation in 3 strings with 74 panels in each. Photovoltaic panels rotate southwards at an angle of 32° above the horizon. The position of photovoltaic panels is given in the graphic illustration. The strings are connected to the main distribution cabinet (MDC), which solar batteries and three-phase inverter are connected with.

3. THE DESCRIPTION OF A PHOTOVOLTAIC SYSTEM

The above-mentioned NPS produces electrical energy by transforming solar energy into the electrical one in the photovoltaic panels. The photovoltaic panels with maximum operating voltage U_{mp}=30.40V and the current I_{mp}=8.9A are mounted on the required structure on the existing roof structure, connected in strings consisting of 74 panels. The panels are exposed to the weather influences and thus susceptible to soiling. In order to maintain the guaranteed level of usability, it is necessary to clean the panels regularly at least once in 6 months. Basic characteristics of a facility for electrical energy production (NPS technical parameters) are given in the table 2.

Table 2. Basic characteristics of a facility for electrical energy production

Number of photovoltaic panels	222
Photovoltaic panel type	Sharp 270
Installed power	59.94kW
Number of inverters	3
Inverter type	Growat 20000UE
Maximum installed power (AC side)	60 kVA
Number of inverters	3

Basic element in every photovoltaic system is a photovoltaic panel. Every panel consists of great number of photovoltaic cells, which are connected both as a series and a parallel so as to obtain the required voltage, that is, the power. Their basic characteristics are long exploitation period, high efficiency level, as well as high resistance to mechanical and weather influences. The most important factor, which influences the production of electrical energy of every module is its power. The power of every panel increases with the temperature decrease and vice versa, it decreases with the temperature rise. Sharp 270 photovoltaic panels manufactured in Germany are used in order to construct this solar field. The panel consists of 60 polycrystalline photovoltaic cells set in an anodized aluminium housing. These cells are tested in terms of quality in each production step and with warranty of ten years. Selected panels have following characteristics when exposed to the radiation of 1000W/m^2, spectral distribution AM 1.5, temperature of 25°C (in accordance with EN 60904 – 3), which is given in the table 3, whereas the image 5 represents an illustration of a Sharp 270 photovoltaic panel.

Table 3. Characteristics of a Sharp 270 photovoltaic panel

Maximum power P_{max}	270 Wp
Maximum operating voltage V_{mp}	30.40 V
Maximum operating current I_{mp}	8.90 A
Open circuit voltage V_{OC}	35.60 V
temperature coefficient P_{max}	-0.45 %/°C
Temperature coefficient V_{OC}	-0.34 %/°C
Temperature coefficient I_{sc}	0.05 %/°C

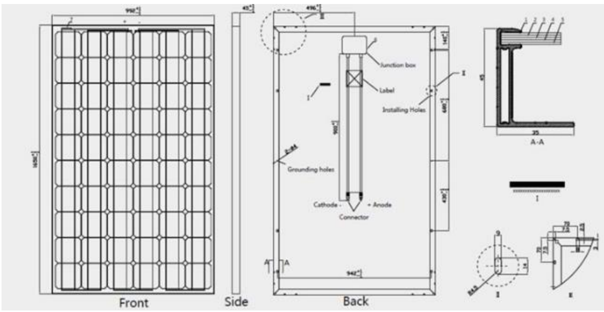

Image 5. Representation of a Sharp 270 photovoltaic panel manufactured in Germany

4. GROWAT 20kW UE INVERTER

The purpose of an inverter in a solar system is to transform direct current voltage, obtained from the photovoltaic panels and batteries, into sinusoidal alternating voltage of regular intensity and frequency, identical to the low voltage of the distribution network.
Selected inverter is a three-phase inverter. Technical characteristics of the designed inverters are given in the table 4. A block diagram of the NPS is shown in the image 6.

Table 4. Growat 20000UE inverter characteristics

Maximum peak power	20kVa
Maximum DC voltage	2000W
Maximum output power	20kW
Output AC voltage range	3/N/PE 230V/400V
Maximum output AC current	32A
Maximum efficiency	98%
European efficiency	97.5%
Output frequency range	50/60Hz - 6Hz/+5Hz
Current distortion THD	3%
Cos φ	0.8
Protection level	IP65
Dimensions	840/740/435
Weight	81kg

Image 6. A block diagram of the NPS for the printing house ”APM Print“, New Belgrade

The application of the SRPS IEC 60364 – 5 – 51 standard includes equipment selection and its installation. This standard provides common rules for compliance with protection measures for safety, requirements for the proper functioning according to the intended usage of the installation, and requirements corresponding to the anticipated external factors. Equipment selection considering the external factors is necessary, not only for the proper functioning but also for the provision of protection measures reliability for safety in accordance with the IEC 60364 rules in principle. Protection measures achieved through equipment design are valid only in the given conditions of the external factors if the required equipment specification tests are conducted under those conditions of the external factors. The characteristics required for the equipment in the function of the external factor class are listed in the table 6.

Table 6. Required characteristics for equipment selection and installment on the basis of the external factors

CODE	DESCRIPTION	EXTERNAL FACTOR	REQUIRED CHARACTERISTICS FOR EQUIPMENT SELECTION AND INSTALLATION
Environmental impact			
AC1	Altitude	≤ 2000m	Normal
AD1	Presence of water	Negligible	Probability of the presence of water is negligible IEC 60721 –3 – 4
AE1	Presence of alien solid bodies or particles	Negligible	Quantity or nature of dust or alien bodies is not significant IEC 60721 – 3 – 3, IEC 60721 – 3 – 4, IEC 60529
AF1	Presence of corrosive substances or pollutants	Negligible	Quantity or nature of corrosive substances or pollutants is not significant IEC 60721 – 3 – 3, IEC 60721 – 3 – 4
AG1	Mechanical impact	Low intensity	Normal
AH1	Vibrations	Low intensity	Normal
AK1	Presence of flora and/or mold growth	Negligible	Normal
AL1	Presence of fauna	No danger	Normal
AM1	Conduction or radiation	Negligible	Normal
AN1	Solar radiation	Low	Normal
AQ2	Atmospheric discharge	Normal	>25 days a year

CODE	DESCRIPTION	EXTERNAL FACTORS	REQUIRED CHARACTERISTICS FOR EQUIPMENT SELECTION AND INSTALLATION
Utilization			
BA1	Human capability	Regular	Normal
BC1	Human contact with soil potential	None	Normal
BD1	Conditions for evacuation in case of emergency	Low population density, Good conditions for evacuation	Normal
BE1	Nature of processed or stored materials	No significant risks	Normal
Facility construction			
CA1	Construction materials	Non-flammable	Normal
CB1	Building plan	Negligible risks	Normal

On the basis of the previously conducted classification of the external factors, the required equipment is selected in accordance with valid standards.

The cross section of a cable line is selected on the basis of permanently permissible currents in accordance with valid standards. Ambient temperature at which the cables are laid corresponds to the temperature values for which the standard prescribes permanently permissible currents (20°C for the cables laid into the soil, and 30°C for the cables in the air), so that the adopted temperature correction factor is k_t=1. As for the feeding cables, it is taken into consideration that they should be laid in a trench or in the cable ducts sunken in a trench in the soil cathegorized as "dry land", whose thermal resistance is not higher than 1mK/W, so the correction factor for the thermal resistance of the soil is k_λ=1.18 (SRPS IEC 60364 – 5 – 52). In case of the parallel cable routing of more than one cable, the standard prescribes the correction factors for group circuitry, if all cables would be loaded by permanently permissible currents at the same time and long enough to obtain steady state temperature.

The calculation of DC cables – PV solar panels
Photovoltaic panels which are exposed to various weather influences (rain, snow, solar radiation, and high temperatures) are mutually connected with "S – Flex01" conductor – special conductor for that purpose. These high-quality cables are equipped by connectors which are specially designed and manufactured for solar panels. The materials that cables and connectors are made of can endure even the most extreme weather and mechanical influences, and they can also operate reliably and safely for several decades. In compliance with IEC 216, "S – Flex01" solar cables have 8 times longer lifespan than the cables with rubber insulation, and even 32 times longer lifespan than the cables with PVC insulation. Wiring of the solar panels is conducted by using previously measured cables with built-in connectors so that the wiring process itself can be finished very quickly and without additional tools. Cables are red and black so that the visual check of the wiring can be easily done. Manufacturers recommend "S – Flex01" 4mm^2 cables for connecting the panels, and for the connection of the first panel of a string with the MDC.
In that case, maximum current [1] would be:

$$I_{max} = 1.25 \cdot 16.34 = 20.425\,A \qquad (1)$$

For specific conditions and the manner of cable laying, permanently withstand current [2] would be equal to:

$$I_z = k_1 \cdot k_2 \cdot I_{PP} \qquad (2)$$

and the elements of the equation represent the following:
I_Z – permissible current load for the above-mentioned cross section, cable type and distribution line;
I_{PP} – permanently permissible current according to the manufacturer's specifications;
k_1 – temperature correction factor;
k_2 – correction factor for the selected type of distribution.
For the "S – Flex01" 4mm^2 conductor, according to the manufacturing data, permanently permissible current is 55A. Based on the adopted correction factors k_1=0.85 and k_2=0.87, [3] it amounts to:

$$I_Z = k_1 \cdot k_2 \cdot I_{TD} = 0.85 \cdot 0.87 \cdot 55 = 40.6725\,A \qquad (3)$$

Since $I_Z > I_{max}$, it can be concluded that the adopted cross section of the cable meets the required conditions.
On the basis of the manufacturer's specifications of the PV solar panels, open circuit voltage of a single solar panel is U_{OC}=35.6V, whereas short-circuit current is I_{SC}=8.9 A. The values of short-circuit current and open-circuit voltage can be increased in the conditions of higher radiation, and this is why the correction coefficient with the value of 1.25 is adopted. In our case, it equals [4]:

$$U_{OCS} = 1.25 \cdot N_{PS} \cdot U_{OC} = 1.25 \cdot 8 \cdot 35.6 = 356\,V \tag{4}$$

The nominal current of the adopted protective device for one string [5] is:

$$I_{OS} = 25\,A > I_{max} \tag{5}$$

The adopted protective device in this case is a glass fuse (10x38mm) with gPV characteristics and operating voltage up to the 1000 Vdc.
The following condition must be met so that the protective device can operate reliably [6]:

$$1.4 \cdot I_{SC} < I_{OS} < 2.4 \cdot I_{SC} \tag{6}$$

The previous condition is met [7] because:

$$22.876 < 25 < 39.216 \tag{7}$$

The calculation of a voltage drop in DC cables – PV solar panels
The least favourable case is selected for the calculation of voltage drop, in accordance with the situation on the ground. The least favourable – the farthest connection is the first module on a string 1 of a solar field to the connection on the inverter.
Voltage drop [8] to the inverter from the mentioned module amounts to:

$$\Delta U = \sum_i \frac{2 \cdot \rho_i \cdot l_i \cdot I_i}{S_i} \ldots \tag{8}$$

and the elements of the equation represent the following:
ΔU – voltage drop expressed in volts;
ρ_i – specific resistance of a conductor;
l_i – length of a given section;
I_i – amperage on a given section;
S_i – cross section of a conductor on a given section;

$$\Delta U = 2 \cdot 0.0178 \cdot \frac{15 \cdot 16.34}{4} = 2.1813\,V \tag{9}$$

Voltage drop in percentage value [10] is:

$$\Delta u_{\%} = \frac{\Delta U}{U_n} \cdot 100 = \frac{2.1813}{192} \cdot 100 = 1.1361\,\% \tag{10}$$

which represents the value meeting the required conditions.

5. THE CALCULATION OF THE PROTECTION FROM THE ELECTRIC SHOCK

In order to achieve the efficient protection from the *indirect contact*, it is required to select a protective device with the characteristics of the automatic power off protection within a period which does not allow maintaining of the voltage contact higher than 50V of the effective value (SRPS IEC 60364 – 4 – 41). This requirement is satisfied if the following condition [11] is met:

$$I_a \cdot R_A \leq 50 \qquad (11)$$

I_a – current which provides the operation of a protective device (RCD), I_a=0.5A;
R_A – sum of the resistance values of the earthing electrode with the exposed conductive parts and the protective conductor with the exposed conductive parts.
Regarding the fact that differential current of the selected protective device RCD is 40/0.5A, the earthing electrode resistance of the mentioned facility must be $R_A \leq 100\Omega$ so that the protective device can reliably operate when the voltage contacts are higher than or equal to 50V. The protection from *the direct contact* of the parts under voltage in the electrical wiring is planned as a protective insulation with a role to prevent any contact of the parts under voltage. The parts under voltage must be completely covered with insulation which can be removed only by its destruction, and which in normal operation can permanently endure all the mechanical, electric, and thermal influences which it is exposed to. The protection from the direct contact of the parts under voltage in the distribution cabinets is planned so that they must be closed or partitioned off in order to provide IP2X degree of protection at least.

6. TOTAL PRODUCED ENERGY

The mathematical model has provided the values related to the total PV irradiation on an annual basis, as well as total produced PV energy, also calculated on an annual basis (table 7).

Table 7. Total produced energy calculated on an annual basis

Location:	**New Belgrade**
Climate data:	New Belgrade
PV Installed power:	59.94 kWp
Gross/Net roof area:	362.64/362.63 m^2
Total PV irradiation/per year:	545,766kWh
Total produced PV energy/per year:	69,612 kWh

The results obtained by this calculation are a product of a mathematical model. Real values at a desired location may deviate, which depends on the current weather conditions,

efficiency of PV module and inverter, and other factors. Given diagram does not represent and can not replace complete technical plan documentation of a PV solar system.
Using a solar radiation diagram presented in the image 7, a diagram of produced energy for the printing house is obtained by mathematical calculation (image 8).

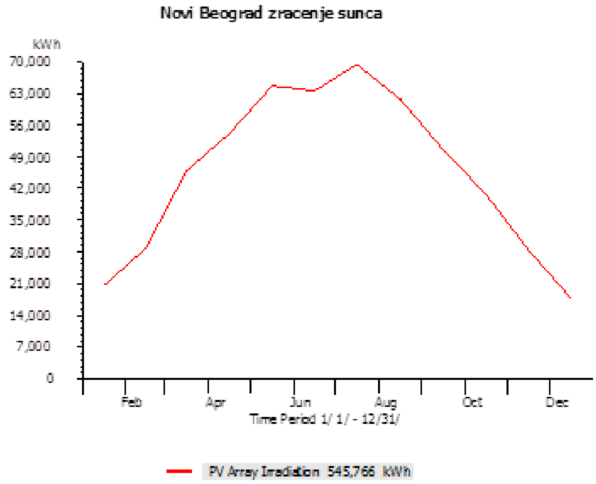

Image 7. A diagram of the solar radiation within a year, measured in New Belgrade

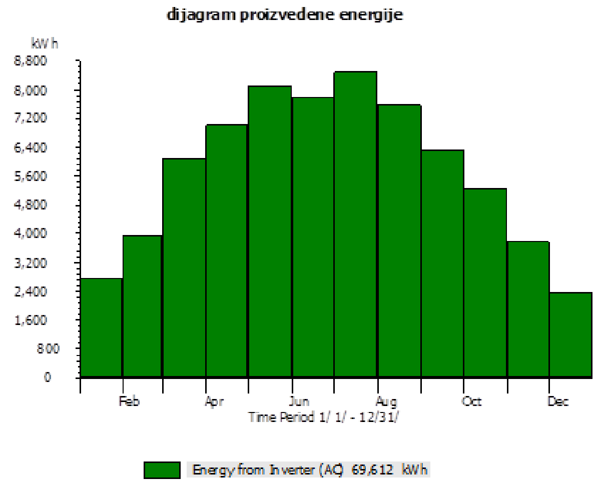

Image 8. A diagram of the produced energy for the printing house "APM Print", New Belgrade

Conducted computer simulations have shown that in given climate and operating conditions it is possible to obtain approximately 69.612 kWh minimum of heat energy out of the solar collector fields on an annual basis. Maximum production is in July, when it amounts to approximately 8.600 kWh, and the minimum is in December, with approximately 2.400 kWh.

7. CONCLUSION

The researches and commercial application in the domain of technologies for the exploitation of solar energy in the heating and electricity production processes in the past decades have resulted in more than enough indicators and practical experiences so that it could be said that these technologies have mostly overcome the basic research and experimental phase, and reached a significant degree of practical applicability and commercial maturity. However, this does not imply that they do not require further researches which will lead to new solutions that are more effective, more technological, and more suitable for wider and further application in practice in everyday life and work – as well as the systems which are reliable and effective enough in terms of usage in various heating processes.

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FSS ZA PROIZVODNJU ELEKTIČNE ENERGIJE IZ SUNČEVOG ZRAČENJA NA KROVU POSTOJEĆEG OBJEKTA "APM PRINT"

Rezime: *Glavnim projektom se predviđa izgradnja objekta za proizvodnju električne energije – mrežni fotonaponski sistem (MPS) na postojećem objektu instalisane snage 60kW.Predviđena je ugradnja solarnih panela proizvođača Sharp, tip 270W.Jedan solarni panel je dimenzija 1650x992x45mm težine 19.0kg. Solarni paneli se montiraju na tipsku laku aluminijumsku konstrukciju tipa ALUMIL SOLAR MOUNTING SYSTEM AS405 proizvođača ALUMIL SOLAR koja je namenjena za instalaciju na industrijske panele.*

Ključne reči*: fotonaponski sistem,električna energija, mrežni fotonaponski sistem (MPS)*