NETWORK-CONNECTED PHOTOVOLTAIC INSTALLATION FOR ELECTRICITY PRODUCTION FOR THE TERRITORY OF SOFIA

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ABSTRACT. The article analyses the possibility of designing a photovoltaic power plant for a family house, which is connected to an existing low voltage / LV / electricity distribution network in Sofia with a capacity of 100 kWp, orientation 0°, gradient 30°, and with Si-poly photovoltaic modules. The PVSyst software was used. The most effective option for building the system was chosen: P50 from the three variants of the Poly 285 Wp 72 cells module offered - P50, P90, and P95. The time for investment return in years (pay-back) has been determined at the purchase price of the produced electricity: 0.40 BGN / kWh (fixed feed-in tariff).

Key words: grid connection, photovoltaic power plant, photovoltaic modules, investment, carbon emissions

МРЕЖОВОСВЪРЗАНА ФОТОВОЛТАИЧНА ИНСТАЛАЦИЯ ЗА ПРОИЗВОДСТВО НА ЕЛЕКТРОЕНЕРГИЯ ЗА ТЕРИТОРИЯТА НА ГР. СОФИЯ

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РЕЗЮМЕ. В статията се разглежда възможност за проектиране на фотоволтаична електроцентрала за фамилна къща, която е свързана към съществуваща електроразпределителна мрежа за ниско напрежение /НН/ на територията на гр. София с мощност 100 kWp, ориентация 0°, наклон 30° и с фотоволтаични модули Si-poly. Използван е програмния продукт PVSyst.

Избран е най-ефективният вариант за изграждане на с-мата: P50 от предложените три разновидности на модула Poly 285 Wp 72 cells - P50, P90 и P95. Определено е времето за възвръщане на инвестицията в години (pay-back) при цена на изкупуване на произведената електрическа енергия: 0.40 лв. /kWh (fixed feed-in tariff).

Ключови думи: мрежово свързване, фотоволтаична електроцентрала, фотоволтаични модули, инвестиция, въглеродни емисии

Introduction

The continuing and deepening energy deficit of fossil fuels in the European countries, including Bulgaria, is growing. The economic dependence of the European states on the countries-exporters of oil, natural gas, and other deficient primary energy sources is increasing. The war in Ukraine has aggravated this problem. In this regard, the preparation of a new program for the development of renewable energy sources in Europe has begun. It envisages a sharp increase in the share of alternative and renewable sources in meeting the energy and fuel needs of the European countries. The Bulgarian domestic economic policy, which stimulates the development of the sector of naturally renewable energy sources is in line with the already existing and the new, even stricter, policy of limiting fossil non-ecological energy sources. Regardless of Europe's priority goal of creating competitive, sustainable, and secure power engineering, economic reasons are forcing the Bulgarian government to frequently change its regulations related to renewable energy sources, and seek to limit more expensive energy solutions, involving photovoltaic systems /PS/, despite their long-term beneficial effect (Law on Energy from Renewable Sources, effective from 05.07.2013).

In the present work, a photovoltaic on-grid power plant for a family house has been designed, which is connected to an existing low voltage electricity distribution network /LV/ on the territory of Sofia city with a power of 100 kWp, orientation 0°, gradient (slope) 30°, and with Si-poly photovoltaic modules (Vassilev Hr.et al., 2006). The PVSyst software product was used. The time for investment return in years (pay-back) at the purchase price of the produced electricity of has been determined: BGN 0.40 /kWh (fixed feed-in tariff) (Am Andonov et al., 2009).

Object of research

The object of research in the present development is a photovoltaic on-grid power plant, designed using the PVSyst software product (http:// www.pvsyst.com).

1. Nature

The photovoltaic power plant directly converts solar energy into electricity for general use, including for supplying electricity to the low voltage power network.

The photovoltaic converters of solar energy (photovoltaics, PV-panels) are made as elements with a certain area, and are called solar panels. They are elements that convert solar radiation directly into electricity and supply it to the conventional electricity distribution network (Koleva et al., 2003)

Photovoltaic systems form a significant and promising share of RES (renewable energy sources). The free, eco-friendly resource, the favourable regulations, and the incentive mechanisms applied for green technologies in more and more countries around the world are just some of the reasons why in ~~the~~ recent years, the PS have enjoyed increased investor interest, and their use is gradually becoming one of the most dynamically developing directions in the electric power engineering on a global scale.

2. Classification

PS allow classification by various indicators. Depending on the place of installation, the PS can be ground, roof, and built into the building facades, and according to the type of mounting structures - stationary and tracking (follow-up). Solar electrical installations can be autonomous and connected to the power network, and systematisation can be offered depending on their capacity. They are made of photovoltaic panels connected in parallel or in series (http:// www.bzs-solar.de).

When connected in parallel, photovoltaics must have the same idling voltage and, more importantly, have the same voltage at the point of maximum capacity.

When connected in series, the photovoltaic panels must have the same characteristics. If this is not the case, the efficiency of the whole "string" is limited by the photovoltaic panel with lowest quality.

3. Production technologies

Currently, PV cells are produced by different technologies, as the efficiency and cost value of the modules vary depending on the material used and the specific conditions. Photovoltaics can be conditionally distinguished by first, second, and third generation technologies (Dechev, 2009).

The first group includes the silicon technologies, which are currently the most common and are characterised by the highest efficiency and price.

The second category of technologies uses photosensitive materials deposited as a very thin layer on a pad of cheap insulating material. They are characterised by a lower price, but are less effective and have a shorter life.

The third group includes concentrating PV technologies, organic photovoltaics, Grätzel cells, etc., which have not yet gained worldwide popularity.

Poly-crystalline silicon photovoltaic modules were used in the study (Koev, 2011; Velev, et al., 2012).

Concept for model research

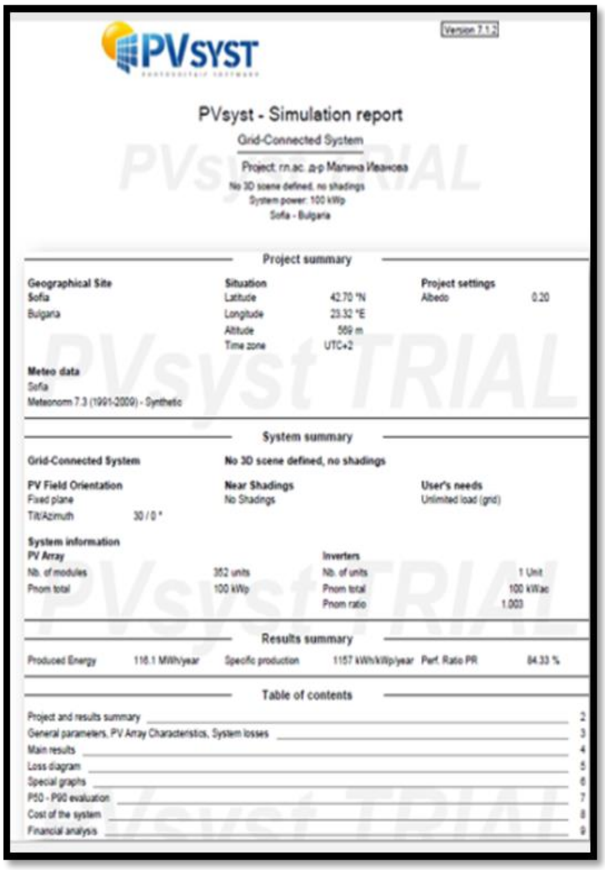
The article considers the possibility of designing a photovoltaic on-grid power plant for a family house, which is connected to an existing low voltage /LV/ electricity distribution network in Sofia with a capacity of 100 kWp, orientation 0°, gradient 30°, and with Si-poly photovoltaic modules.

The PVSyst software was used. The time for return on investment in years will be determined at the purchase price of the produced electricity: 0.40 BGN / kWh.

The following parameters for project simulation /data/ are entered on the program setting screen: for the city of Sofia, capacity 100 kWp, orientation 0°, gradient 30°, photovoltaic modules Si-poly. Additionally, the following are set:

Price of modules: 1 BGN/Wp
Price of inverters: 2 BGN/kW
Other components:
Accessories – 3000 BGN
Cabling (wiring) - 7000 BGN
Training and analysis: Engineering - 3000 BGN
Installation of the plant:
Installation of modules - 10 BGN/module
Installation of inverters - 500 BGN/inverter
Connecting to the network - 10 BGN/kWp
Operating expenses:
Salaries - 24000 BGN/year
Financial parameters:
Own funds - 100000 BGN
Interest on the loan - 3%
It is possible to determine the time for investment return in years (pay-back) at the purchase price of the produced electricity : 0.40 BGN /kWh.

Results obtained


Version 7.1.2

PVsyst - Simulation report
Grid-Connected System
Project: гл.ас. д-р Малина Иванова
No 3D scene defined, no shadings
System power: 100 kWp
Sofia - Bulgaria

Project summary

Geographical Site		Situation		Project settings	
Sofia		Latitude	42.70 °N	Albedo	0.20
Bulgaria		Longitude	23.32 °E		
		Altitude	569 m		
		Time zone	UTC+2		

Meteo data
Sofia
Meteonorm 7.3 (1991-2009) - Synthetic

System summary

Grid-Connected System — No 3D scene defined, no shadings

PV Field Orientation		Near Shadings	User's needs
Fixed plane		No Shadings	Unlimited load (grid)
Tilt/Azimuth	30 / 0 °		

System information

PV Array		Inverters	
Nb. of modules	352 units	Nb. of units	1 Unit
Pnom total	100 kWp	Pnom total	100 kWac
		Pnom ratio	1.003

Results summary

Produced Energy	116.1 MWh/year	Specific production	1157 kWh/kWp/year	Perf. Ratio PR	84.33 %

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Fig.1. Input data and design content

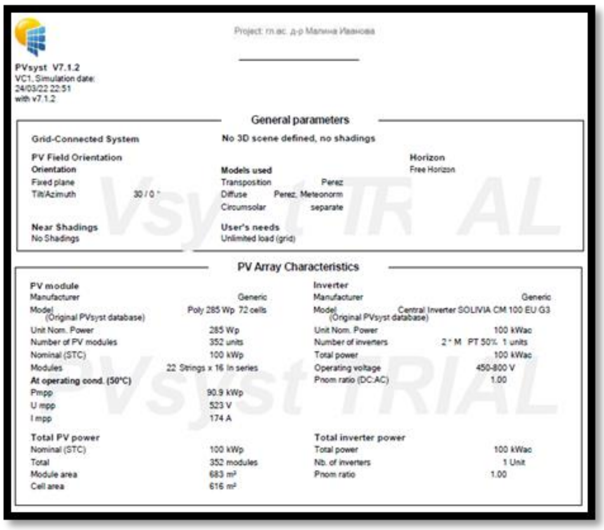


Fig.2. Data on the connected photovoltaic modules / built PV system/

Fig.3. Losses in the system

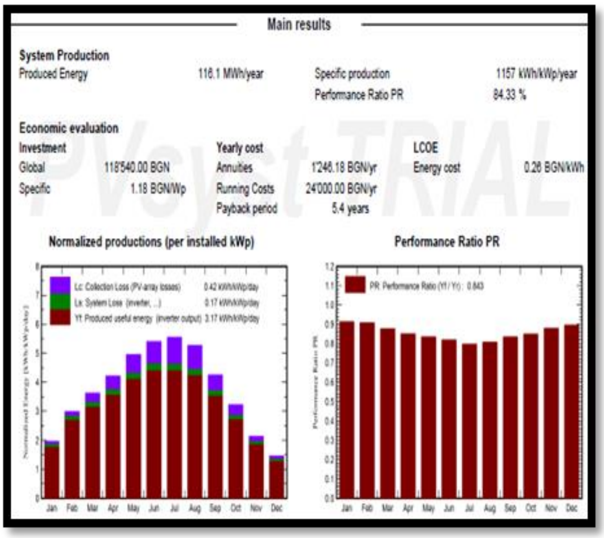
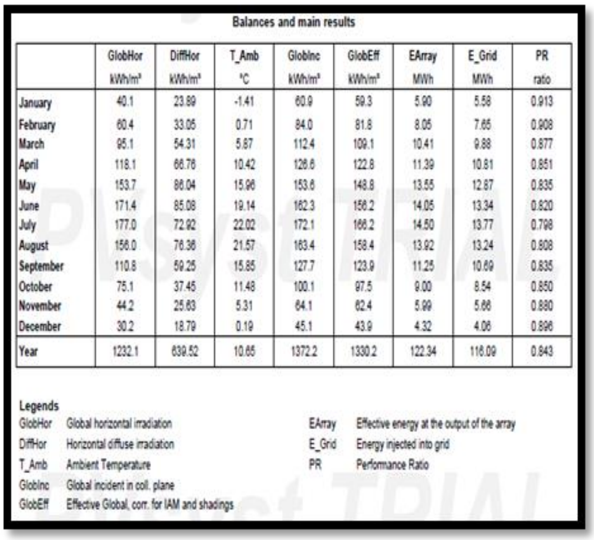


Fig.4. Report on energy production


Balances and main results

	GlobHor	DiffHor	T_Amb	GlobInc	GlobEff	EArray	E_Grid	PR
	kWh/m²	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	ratio
January	40.1	23.89	-1.41	60.9	59.3	5.90	5.58	0.913
February	60.4	33.05	0.71	84.0	81.8	8.05	7.65	0.908
March	95.1	54.31	5.87	112.4	109.1	10.41	9.88	0.877
April	118.1	66.78	10.42	126.6	122.8	11.39	10.81	0.851
May	153.7	86.04	15.96	153.6	148.8	13.55	12.87	0.835
June	171.4	85.08	19.14	162.3	156.2	14.05	13.34	0.820
July	177.0	72.92	22.02	172.1	166.2	14.50	13.77	0.798
August	156.0	76.36	21.57	163.4	158.4	13.92	13.24	0.808
September	110.8	59.25	15.85	127.7	123.9	11.25	10.69	0.835
October	75.1	37.45	11.48	100.1	97.5	9.00	8.54	0.850
November	44.2	25.63	5.31	64.1	62.4	5.99	5.66	0.880
December	30.2	18.79	0.19	45.1	43.9	4.32	4.06	0.896
Year	1232.1	639.52	10.65	1372.2	1330.2	122.34	116.09	0.843

Legends
GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Fig.5. Annual main results by months

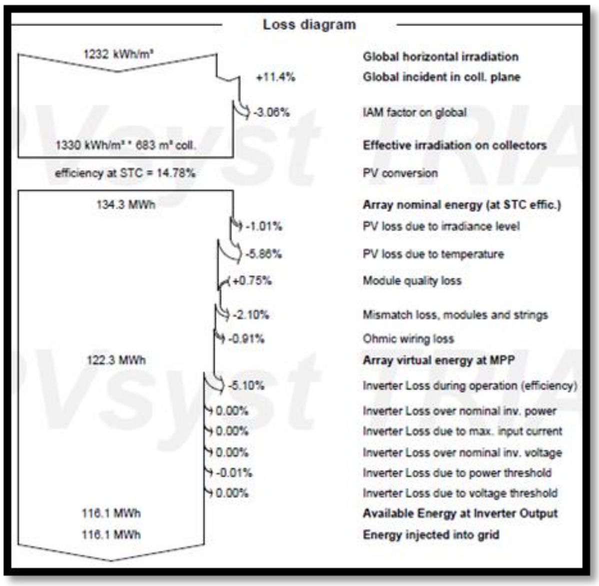


Fig.6. Report of losses from various factors
Losses in the system /modules and inverter/

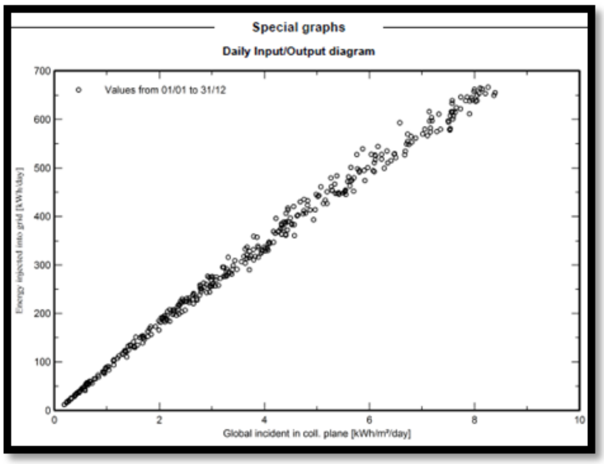


Fig.7. Project simulation parameters - dependence between average daily solar radiation and energy supplied to the network

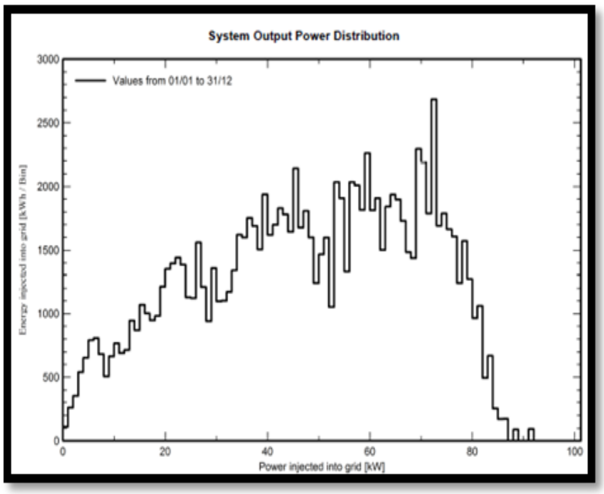


Fig.8. Annual distribution of the output power of the system

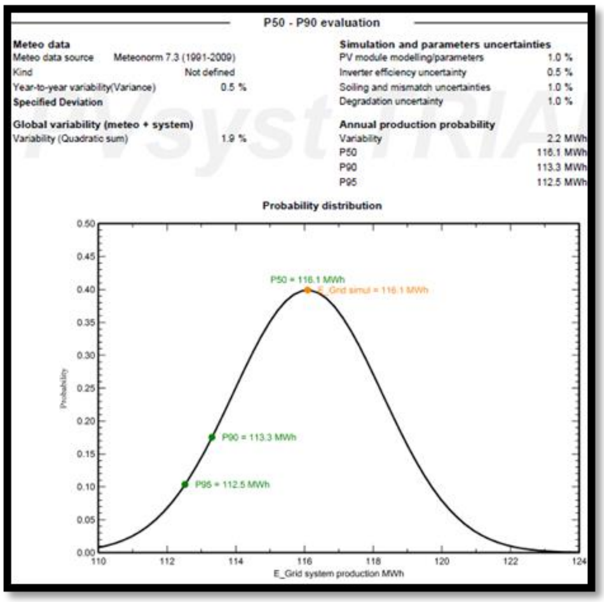
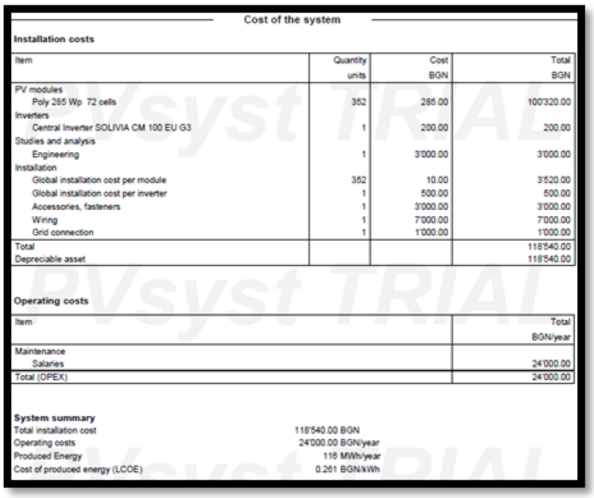


Fig.9. Probability distribution /when building the system with three variants of the module: P50, P90 and P95/



Cost of the system

Installation costs

Item	Quantity units	Cost BGN	Total BGN
PV modules			
Poly 285 Wp 72 cells	352	285.00	100'320.00
Inverters			
Central Inverter SOLIVIA CM 100 EU G3	1	200.00	200.00
Studies and analysis			
Engineering	1	3'000.00	3'000.00
Installation			
Global installation cost per module	352	10.00	3'520.00
Global installation cost per inverter	1	500.00	500.00
Accessories, fasteners	1	3'000.00	3'000.00
Wiring	1	7'000.00	7'000.00
Grid connection	1	1'000.00	1'000.00
Total			118'540.00
Depreciable asset			118'540.00

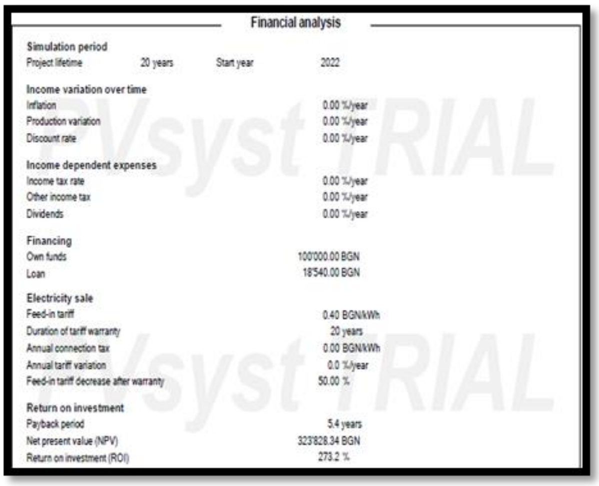
Operating costs

Item	Total BGN/year
Maintenance	
Salaries	24'000.00
Total (OPEX)	24'000.00

System summary

Total installation cost 118'540.00 BGN
Operating costs 24'000.00 BGN/year
Produced Energy 116 MWh/year
Cost of produced energy (LCOE) 0.261 BGN/kWh

Fig.10. Price of the system in BGN and annual production Financial analysis



Financial analysis

Simulation period
Project lifetime 20 years Start year 2022

Income variation over time
Inflation 0.00 %/year
Production variation 0.00 %/year
Discount rate 0.00 %/year

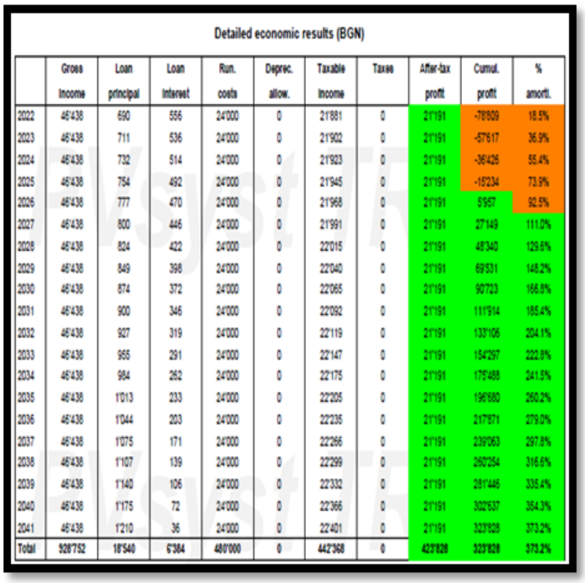
Income dependent expenses
Income tax rate 0.00 %/year
Other income tax 0.00 %/year
Dividends 0.00 %/year

Financing
Own funds 100'000.00 BGN
Loan 18'540.00 BGN

Electricity sale
Feed-in tariff 0.40 BGN/kWh
Duration of tariff warranty 20 years
Annual connection tax 0.00 BGN/kWh
Annual tariff variation 0.0 %/year
Feed-in tariff decrease after warranty 50.00 %

Return on investment
Payback period 5.4 years
Net present value (NPV) 323'828.34 BGN
Return on investment (ROI) 273.2 %

Fig.11. Summary of the result for investment return



Detailed economic results (BGN)

	Gross Income	Loan principal	Loan interest	Run. costs	Deprec. allow.	Taxable income	Taxes	After-tax profit	Cumul. profit	% amorti.
2022	46'438	690	556	24'000	0	21'881	0	21'191	-78'809	18.5%
2023	46'438	711	536	24'000	0	21'902	0	21'191	-57'617	36.9%
2024	46'438	732	514	24'000	0	21'923	0	21'191	-36'426	55.4%
2025	46'438	754	492	24'000	0	21'945	0	21'191	-15'234	73.9%
2026	46'438	777	470	24'000	0	21'968	0	21'191	5'957	92.5%
2027	46'438	800	446	24'000	0	21'991	0	21'191	27'149	111.0%
2028	46'438	824	422	24'000	0	22'015	0	21'191	48'340	129.6%
2029	46'438	849	398	24'000	0	22'040	0	21'191	69'531	148.2%
2030	46'438	874	372	24'000	0	22'065	0	21'191	90'723	166.8%
2031	46'438	900	346	24'000	0	22'092	0	21'191	111'914	185.4%
2032	46'438	927	319	24'000	0	22'119	0	21'191	133'106	204.1%
2033	46'438	955	291	24'000	0	22'147	0	21'191	154'297	222.8%
2034	46'438	984	262	24'000	0	22'175	0	21'191	175'488	241.5%
2035	46'438	1'013	233	24'000	0	22'205	0	21'191	196'680	260.2%
2036	46'438	1'044	203	24'000	0	22'235	0	21'191	217'871	279.0%
2037	46'438	1'075	171	24'000	0	22'266	0	21'191	239'063	297.8%
2038	46'438	1'107	139	24'000	0	22'299	0	21'191	260'254	316.6%
2039	46'438	1'140	106	24'000	0	22'332	0	21'191	281'445	335.4%
2040	46'438	1'175	72	24'000	0	22'366	0	21'191	302'637	354.3%
2041	46'438	1'210	36	24'000	0	22'401	0	21'191	323'828	373.2%
Total	928'752	18'540	6'384	480'000	0	442'368	0	423'828	323'828	373.2%

Fig.12. Annual economic results - gross income, principle of loan, interest on the loan, current expenses, depreciation deductions, taxable income, taxes, profit after tax, Total profit / profitability / over the years

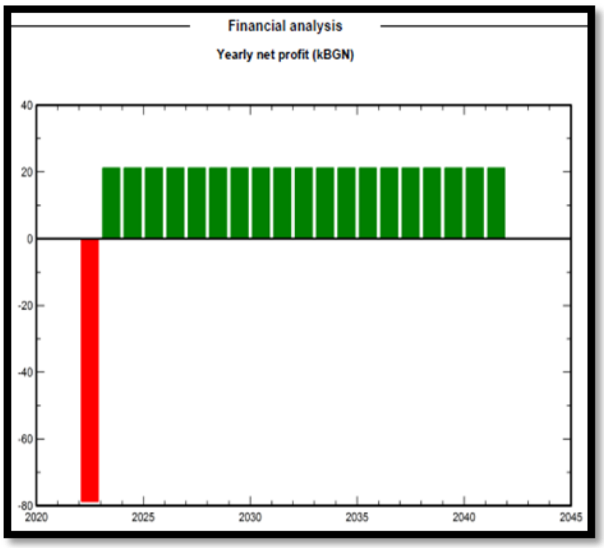


Fig.13. Annual profits

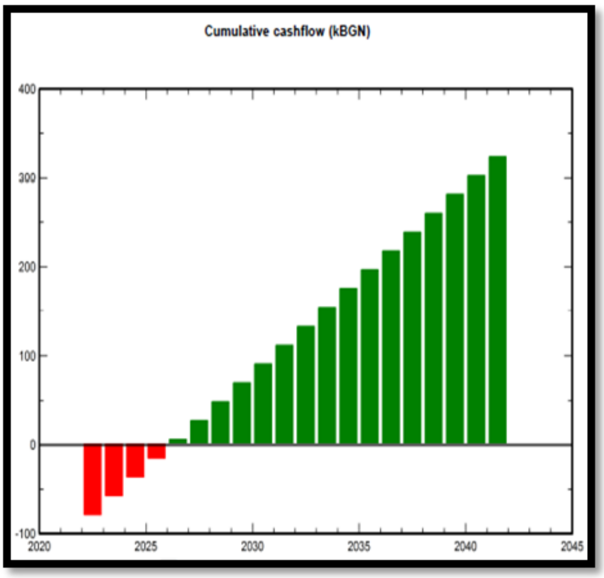


Fig.14. Investment return

Conclusion

A photovoltaic on-grid electric power plant has been designed for a family house, which is connected to an already existing low voltage electricity distribution network /LV/ in Sofia. It is with a capacity of 100 kWp, orientation 0°, gradient 30°, and with Si-poly photovoltaic modules. The PVSyst software was used. The following conclusions were drawn:

- The network-connected photovoltaic power plant consists of 352 photovoltaic modules Poly 285 Wp 72 cells, arranged in 22 strings of 16 modules in a series. It is located on an area of 683 m^2;

- The inverter is central: Central Inverter SOLIVIA CM 100 EU G3]

- From the performed calculations with the three proposed variants of the P50, P90, and P95 polycrystalline photovoltaic modules, the P50 module was chosen;

- The final price of the photovoltaic installation in the amount of BGN 323,828 thousand has been determined. With a service life of 20 years, the investments will be repaid after 5.4 years, and within the service life of the power plant will return by 273.2%;

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http:// www.bzs-solar.de

http:// www.pvsyst.com