XIV INTERNATIONAL SCIENTIFIC CONFERENCE
CONTEMPORARY MATERIALS 2021
Banja Luka, September 10, 2021

ACADEMY OF SCIENCES AND ARTS OF THE REPUBLIC OF SRPSKA

Влада Републике Српске

Министарство науке и технологије

REDUCING CLIMATE CHANGE BY INSTALLING A NEW PHOTOVOLTAIC POWER PLANT IN BULGARIA

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Vice Rector in charge of Research and Development

Technical University of Gabrovo, Bulgaria
Faculty of Electrical Engineering and Electronics

CONTENTS

1. INTRODUCTION

A three new roof-mounted grid-connected photovoltaic (PV) power plants have been constructed in the Technology Park at the Technical University of Gabrovo, Bulgaria, as part of a Project BG05M2OP001-1.002-0023 Competence Center "Intelligent Mechatronic, Eco and Energy Saving Systems and Technologies" (https://smeest.eu), funded by an Operational Programme Science and Education for Smart Growth, co-financed by the European Union through the European Structural and Investment Funds.

The photovoltaic power plants are part of the equipment of the new laboratory section "Ecological, energy saving and electromagnetically compatible lighting, LED and RES components and technologies", in which scientists and specialists of one of the largest centers for research of photovoltaic systems in Bulgaria - Technical University - Gabrovo are engaged.

Technology Park at the Technical University of Gabrovo, Bulgaria

1. INTRODUCTION

Three different types of technology of the PV modules have been used: mono-crystalline silicon (mono-Si), cadmium telluride (CdTe) and copper indium gallium selenide (CIGS). With the new three power plants, together with the existing photovoltaic power plants in TU-Gabrovo with modules of amorphous silicon and poly-crystalline silicon, **5 different photovoltaic materials can be tested simultaneously**. A small 500 Wp mono-Si photovoltaic thermal hybrid solar collectors (PVT) PV system is also constructed.

The power plants are equipped with a system for monitoring the meteorological and electrical operating parameters, which measures, displays and stores data on solar radiation, temperature, wind speed, currents, voltages, and electrical power of each power plant.

2. TECHNICAL CHARACTERISTICS OF THE USED mono-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

Three different types technology of the PV modules

- **Monocrystalline silicon (mono-Si) – 44 pieces PV modules, 10 kWp**
- **Cadmium telluride (CdTe) – 96 pieces PV modules, 9.6 kWp**
- **Copper indium gallium selenide (CIGS) – 90 pieces PV modules, 9.9 kWp**

Disposition of the three PV power plants on the roof of the Competence Center building at The Technology center of Technical University of Gabrovo

2. TECHNICAL CHARACTERISTICS OF THE USED mono-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

Technical data at standard test conditions (STC) of the three different types technology of the PV modules

Parameters at STC*	**m-Si** by Risen, model SYP250M	**CdTe** by Calyxo, model CX4 100/3	**CIGS** by Hulket, model 1100E1
Nominal power, [Wp]	250.00	100.00	110.00
Voltage at maximum power, [V]	30.40	72.60	56.90
Current at maximum power, [A]	8.25	1.38	1.93
Open circuit voltage, [V]	37.50	72.60	73.40
Short circuit current, [A]	8.59	1.53	2.10
Maximum system voltage, [Vdc]	1000	1000	1000

***Standard test conditions:**

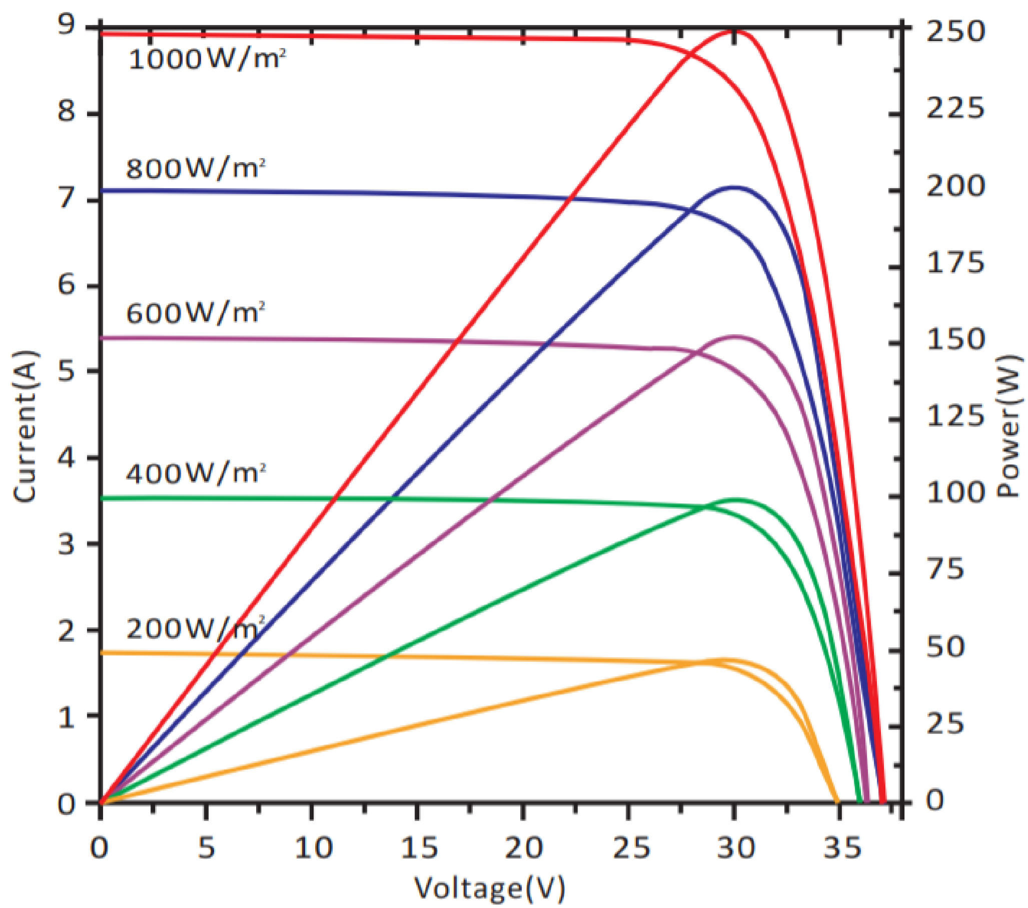
- Solar irradiance: 1000 W/m^2
- Mass of the air: AM 1.5
- Temperature of the PV cell: Tc = 25 °C

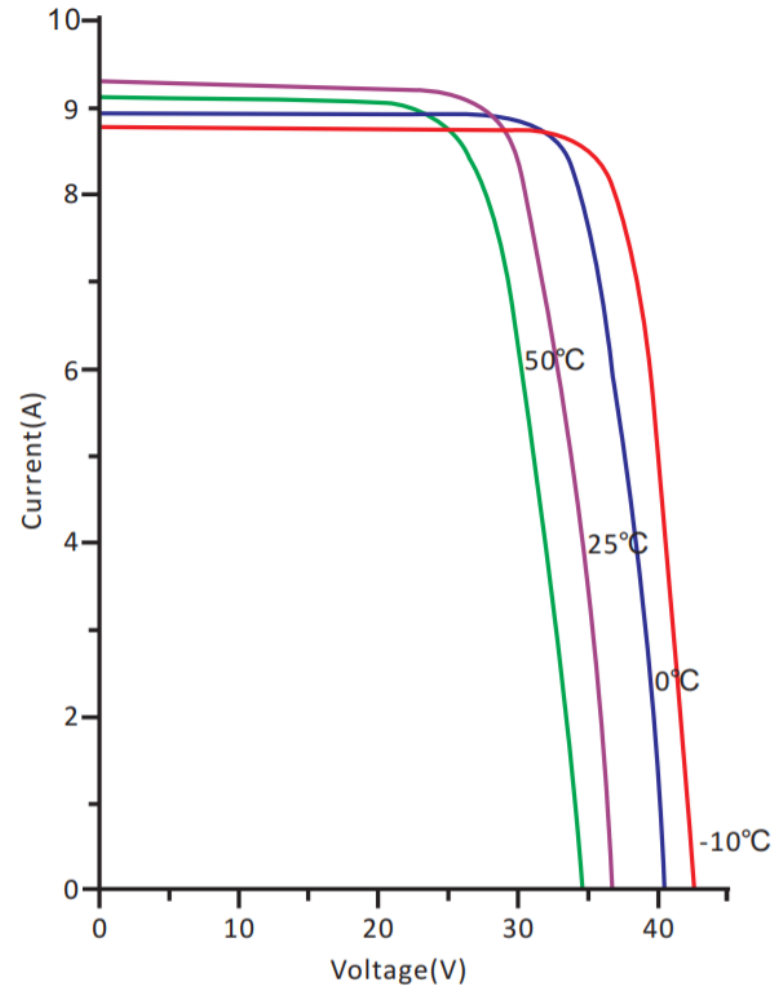
2. TECHNICAL CHARACTERISTICS OF THE USED mono-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

mono-Si PV modules power plant

2. TECHNICAL CHARACTERISTICS OF THE USED m-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

I-V and P-V curves of the mono-Si PV module at different irradiation ans cell temperatures



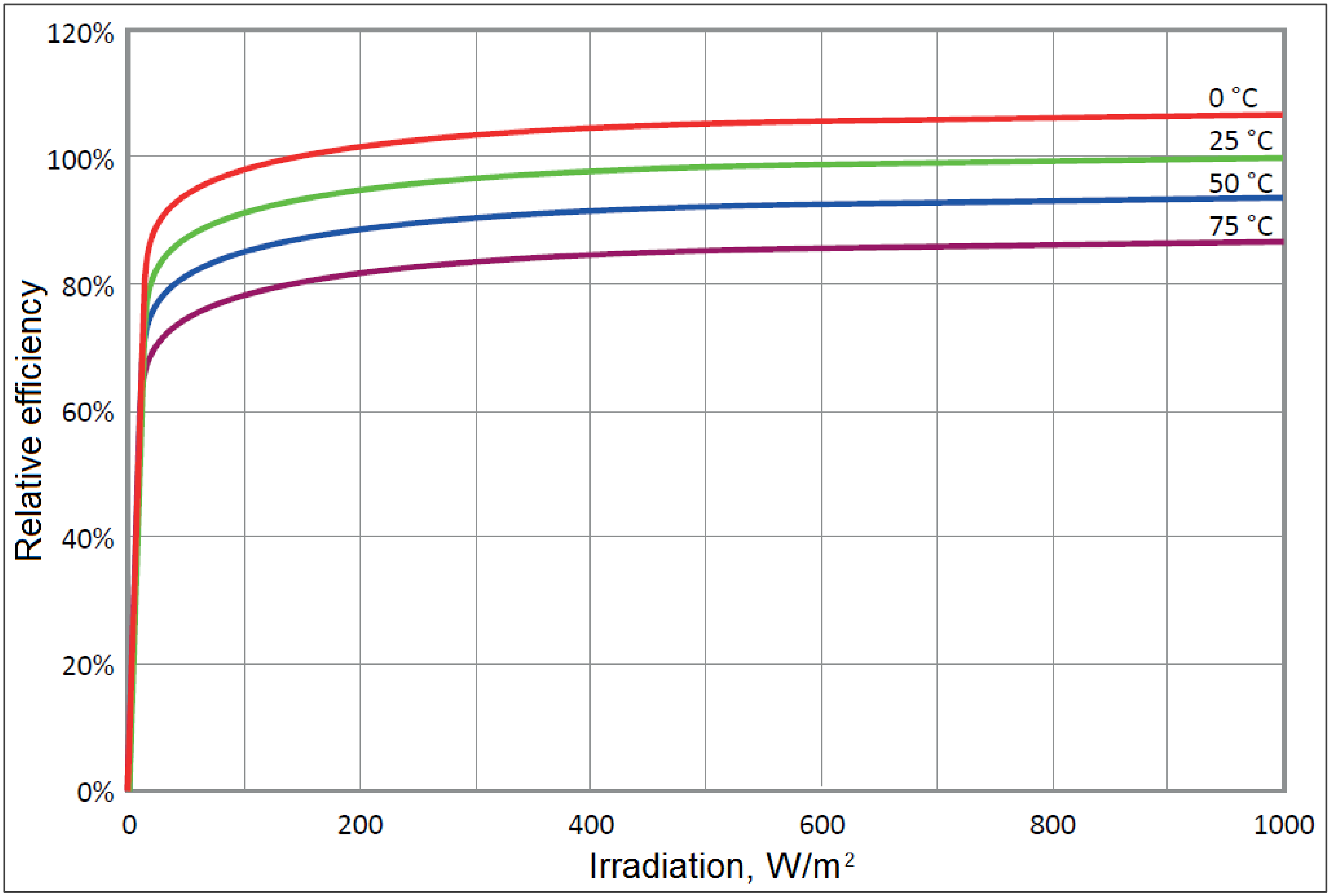


2. TECHNICAL CHARACTERISTICS OF THE USED mono-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

CdTe PV modules power plant

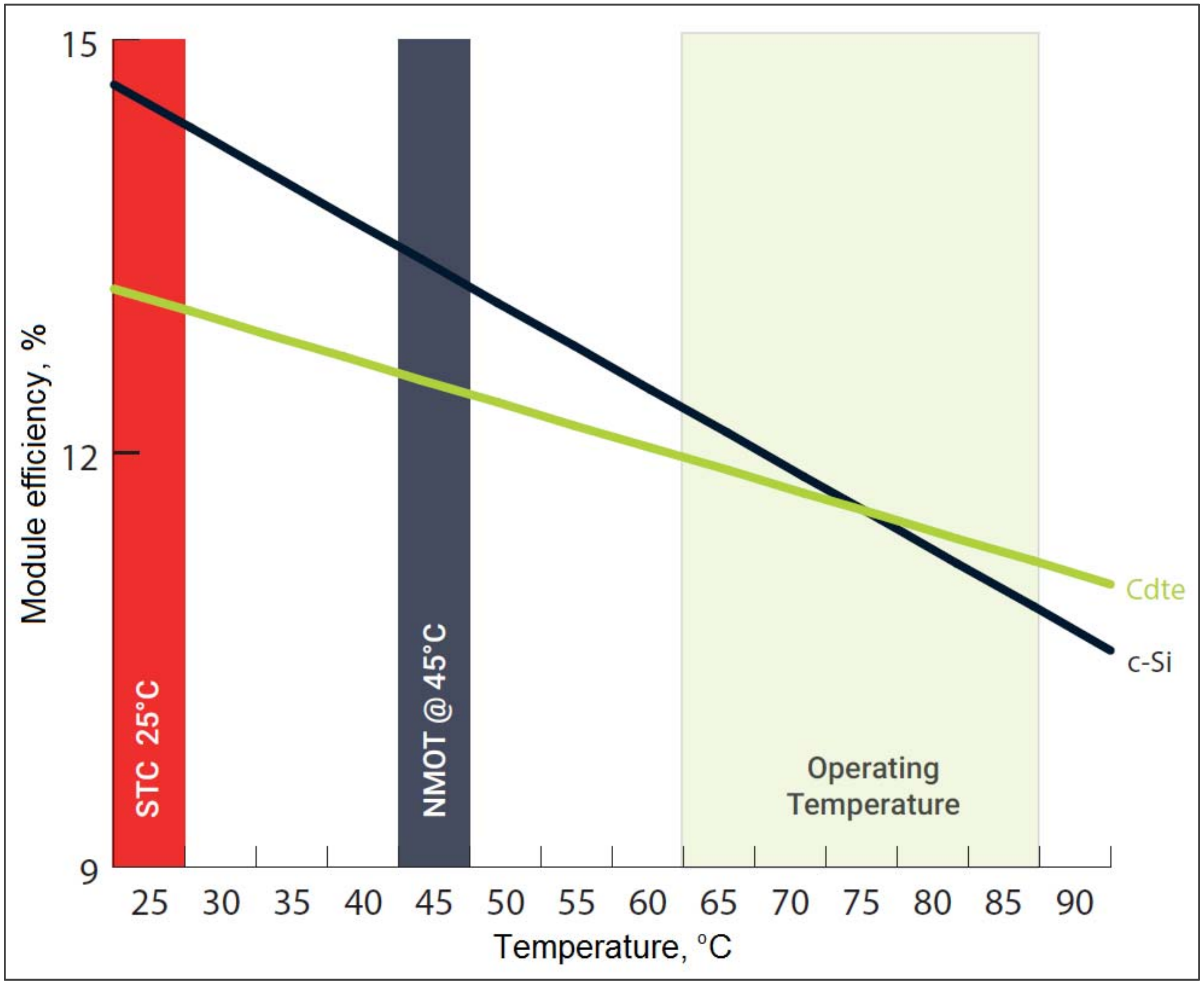
2. TECHNICAL CHARACTERISTICS OF THE USED m-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

Performance at different solar irradiation of the CdTe PV module 100 Wp



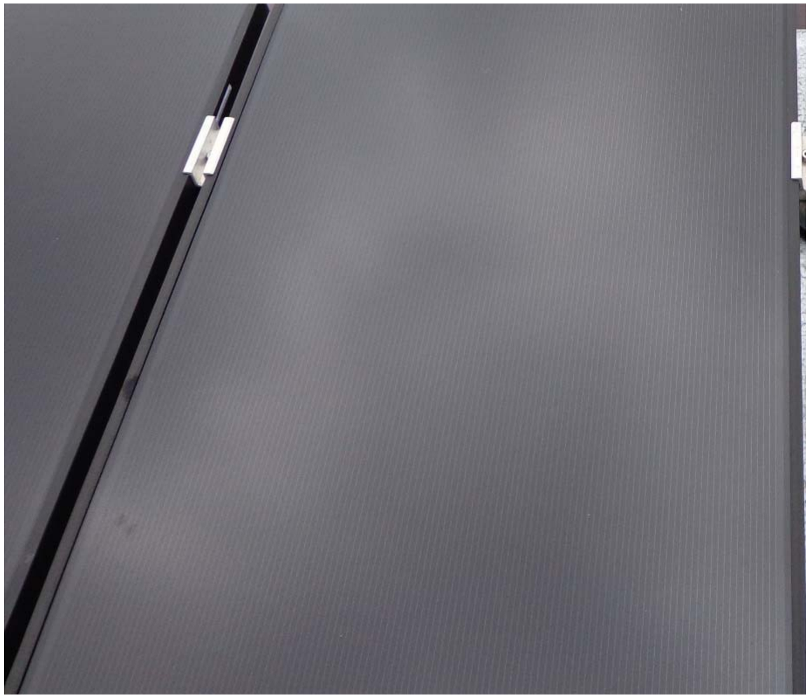
2. TECHNICAL CHARACTERISTICS OF THE USED m-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

Comparative efficiency at different temperature of the PV cell between CdTe and crystalline silicon material



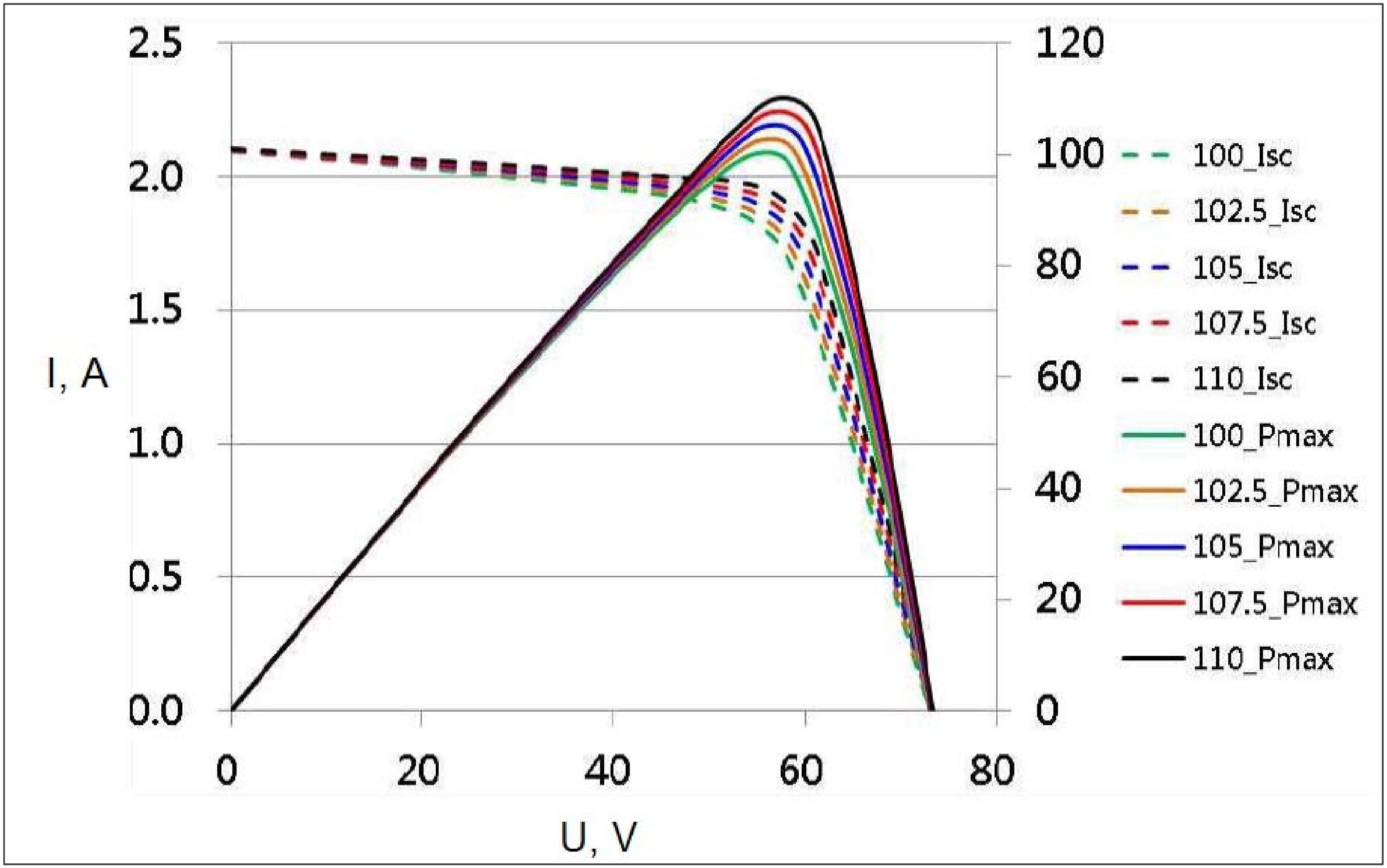
2. TECHNICAL CHARACTERISTICS OF THE USED mono-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

CIGS PV modules power plant



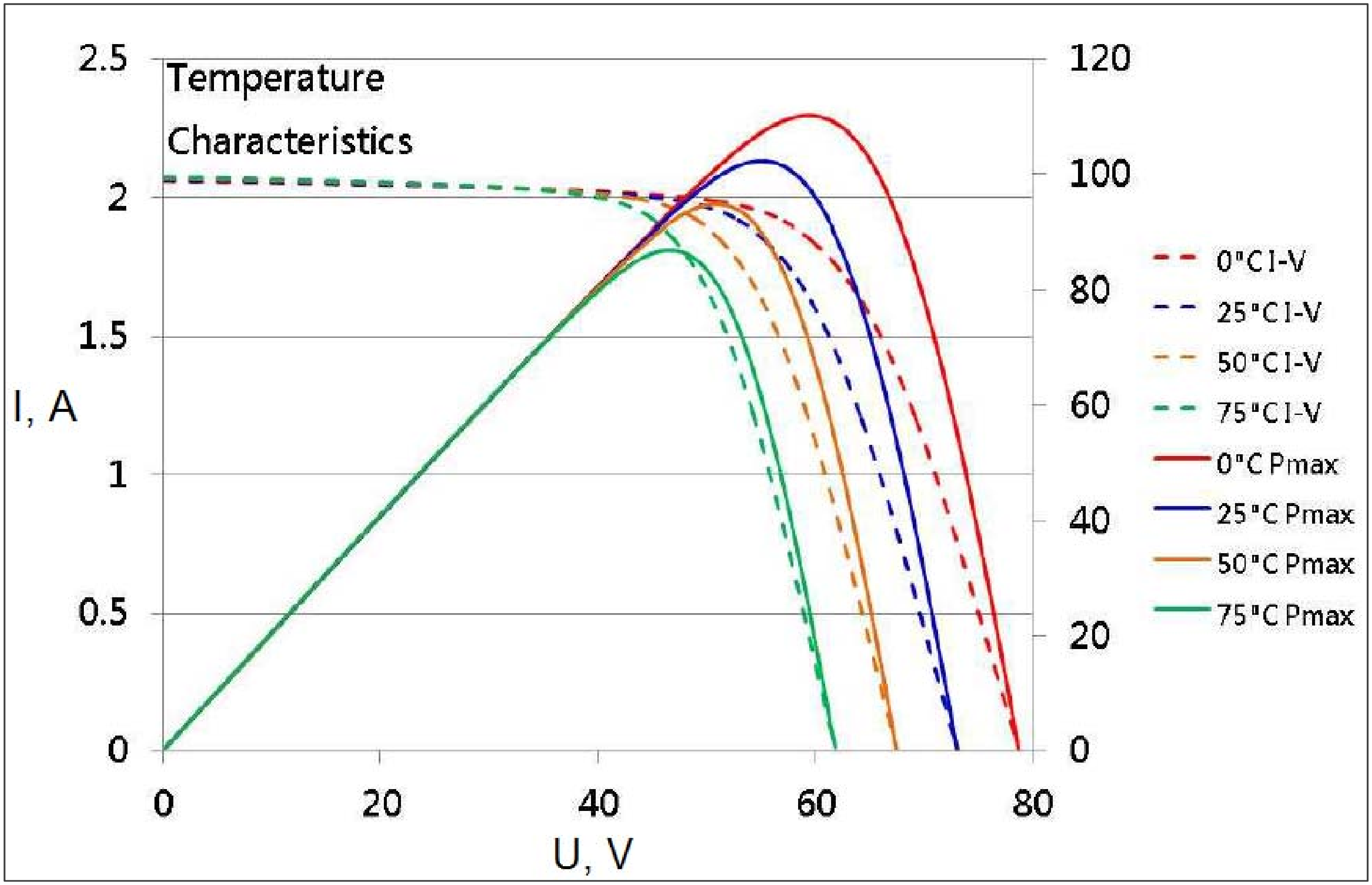
2. TECHNICAL CHARACTERISTICS OF THE USED m-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

I-V and P-V curves of the CIGS PV module at STC



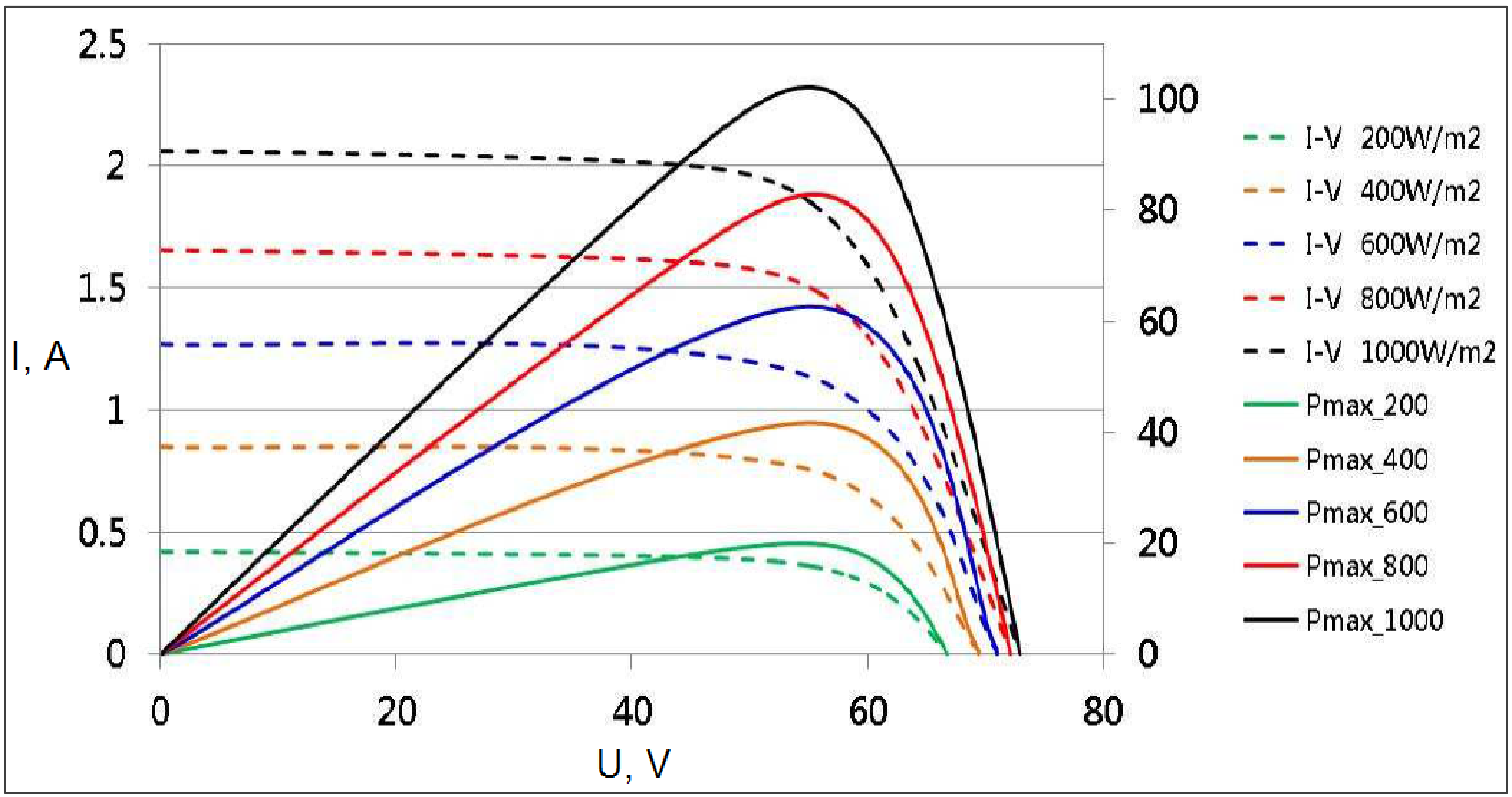
2. TECHNICAL CHARACTERISTICS OF THE USED m-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

I-V and P-V curves of the CIGS PV module at various temperature



2. TECHNICAL CHARACTERISTICS OF THE USED m-Si, CdTe AND CIGS PHOTOVOLTAIC MODULES

I-V and P-V curves of the CIGS PV module at various irradiance



2. THREE-PHASE SINE-WAVE INVERTERS AND SMART LOGGER

Huawei SUN2000-10KTL-M0

Smart logger Solar Log 300

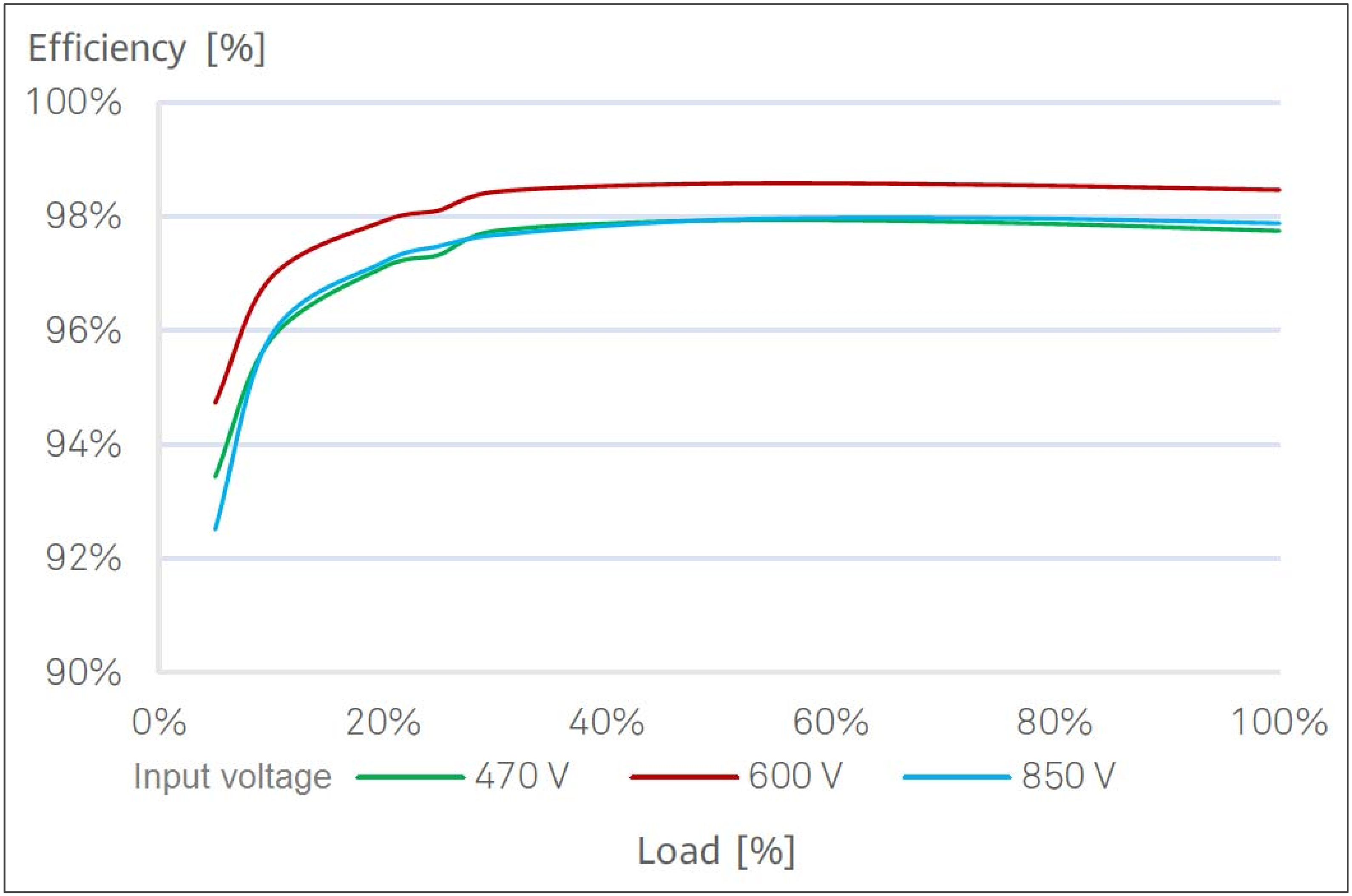
2. TECHNICAL CHARACTERISTICS OF THE THREE-PHASE SINE-WAVE INVERTERS

Inverters Huawei, model SUN2000-10KTL-M0

Input		Output	
Maximum PV power	14 880 Wp	Grid connection	3 phase
Maximum voltage	1 100 Vdc	Rated output power	10 kW
Operating voltage range	(140 ÷ 980) V	Maximum apparent power	11 kVA
Start-up voltage	200 V	Rated output voltage	230/400 Vac
Full power MPPT voltage range	(470 ÷ 850) V	Rated AC grid frequency	50 Hz
Rated input voltage	600 V	Maximum output current	16.9 A
Maximum input current / MPPT	11 A	Adjustable power factor	0.8 ind ÷ 0.8 cap
Maximum short-circuit current	15 A	Maximum total harmonic distortion (THD)	≤ 3 %
Number of MPP trackers	2	Maximum efficiency	98.6 %
Maximum number of inputs	2		

2. TECHNICAL CHARACTERISTICS OF THE THREE-PHASE SINE-WAVE INVERTERS

Efficiency curves of the inverter SUN2000-10KTL-M0



2. ADDITIONAL LABORATORY MEASURING EQUIPMENT

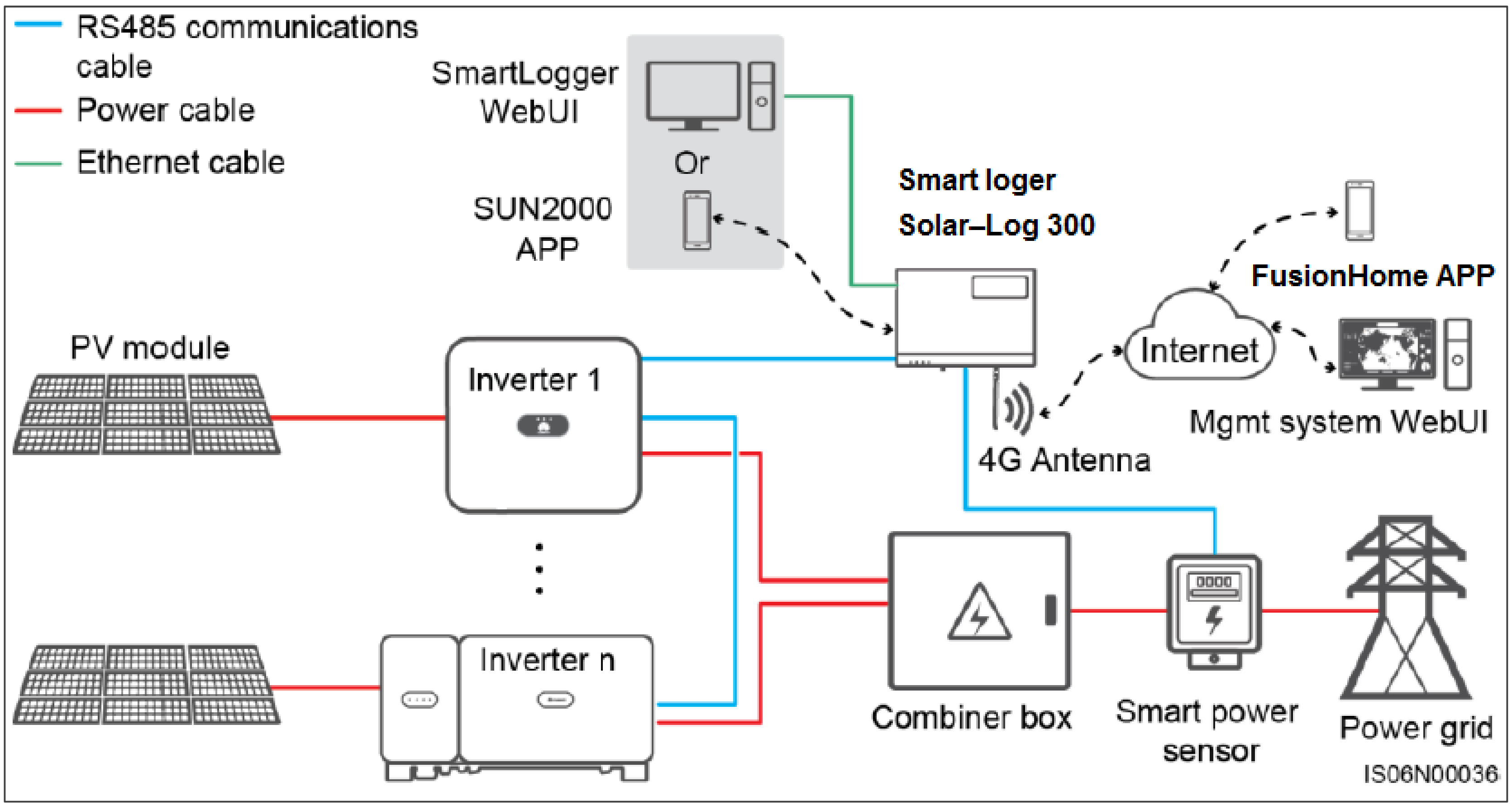
I-V curve meter
DC voltage up to 1500 V

Thermal inspection
infrared camera

Power quality analyzer
class A

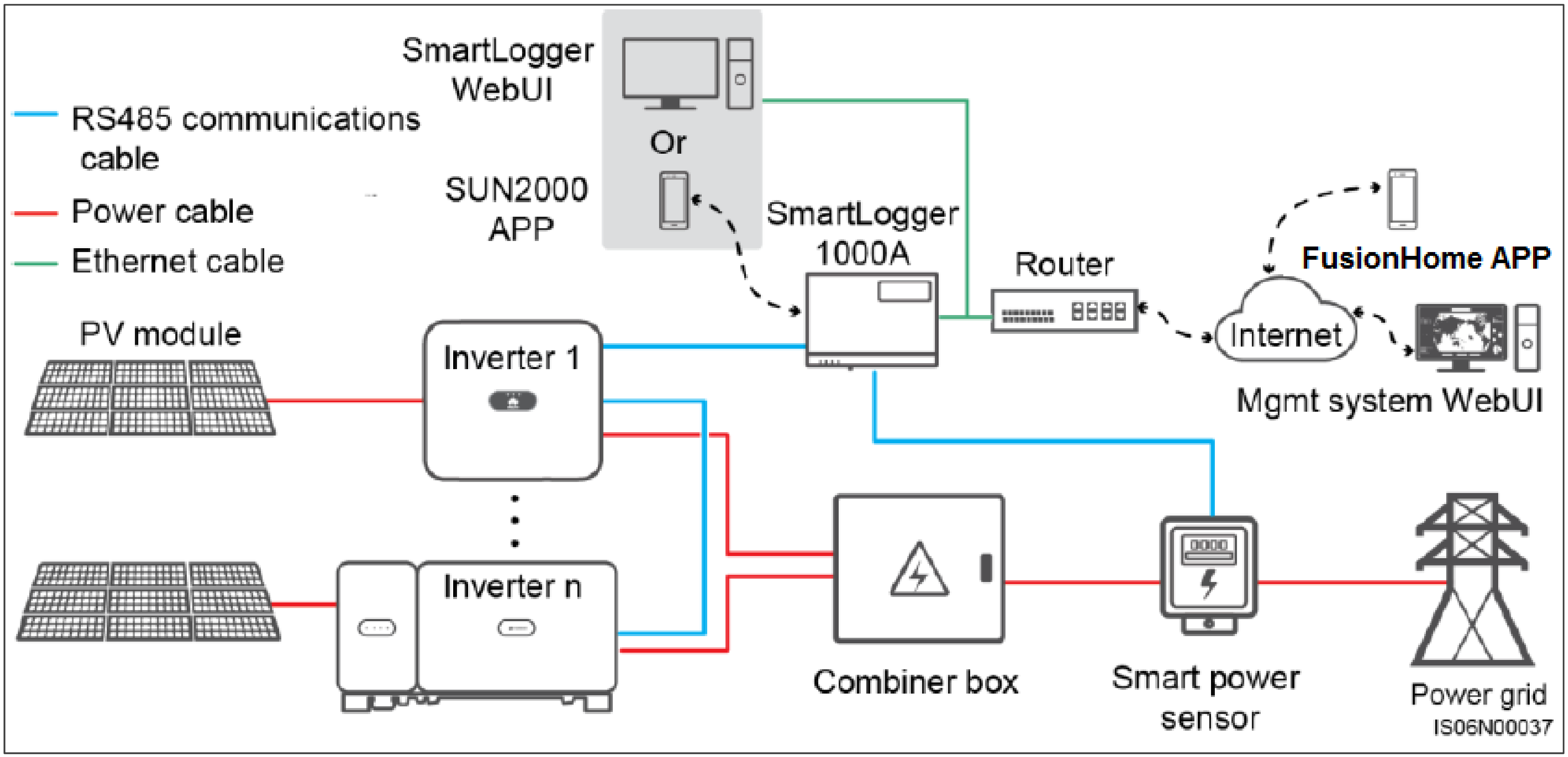
2. TECHNICAL CHARACTERISTICS OF THE THREE-PHASE SINE-WAVE INVERTERS

Communications with the Inverters and Smart logger Access over a Public Network



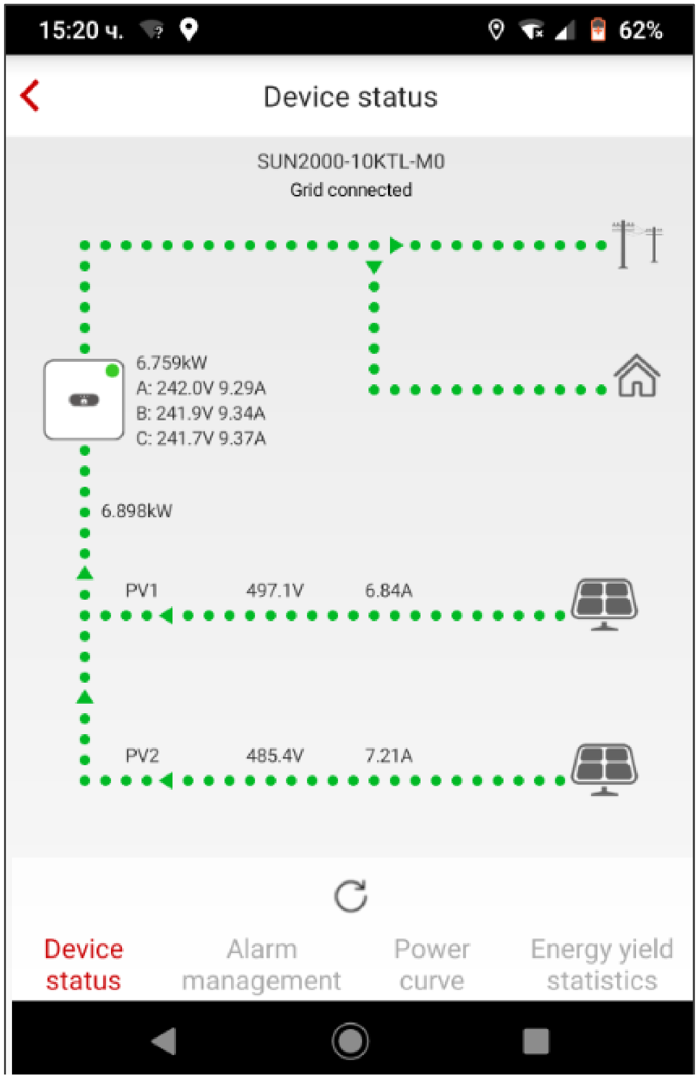
2. TECHNICAL CHARACTERISTICS OF THE THREE-PHASE SINE-WAVE INVERTERS

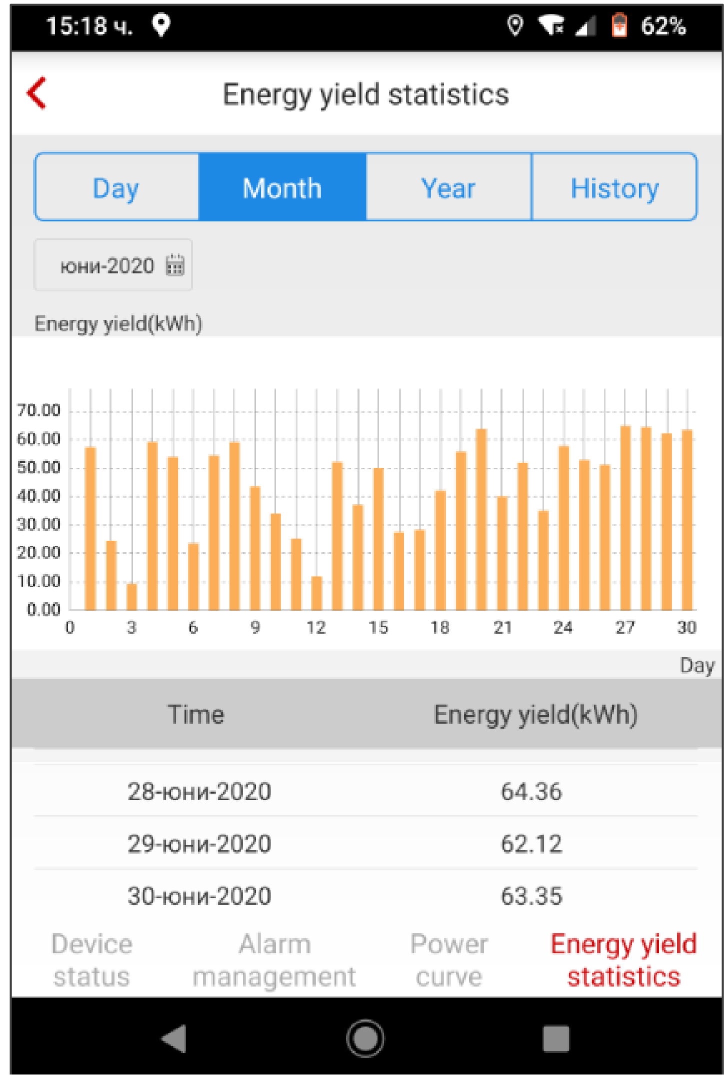
Communications with inverters SUN2000-10KTL-M0
Access over a Local Ethernet and WiFi



3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

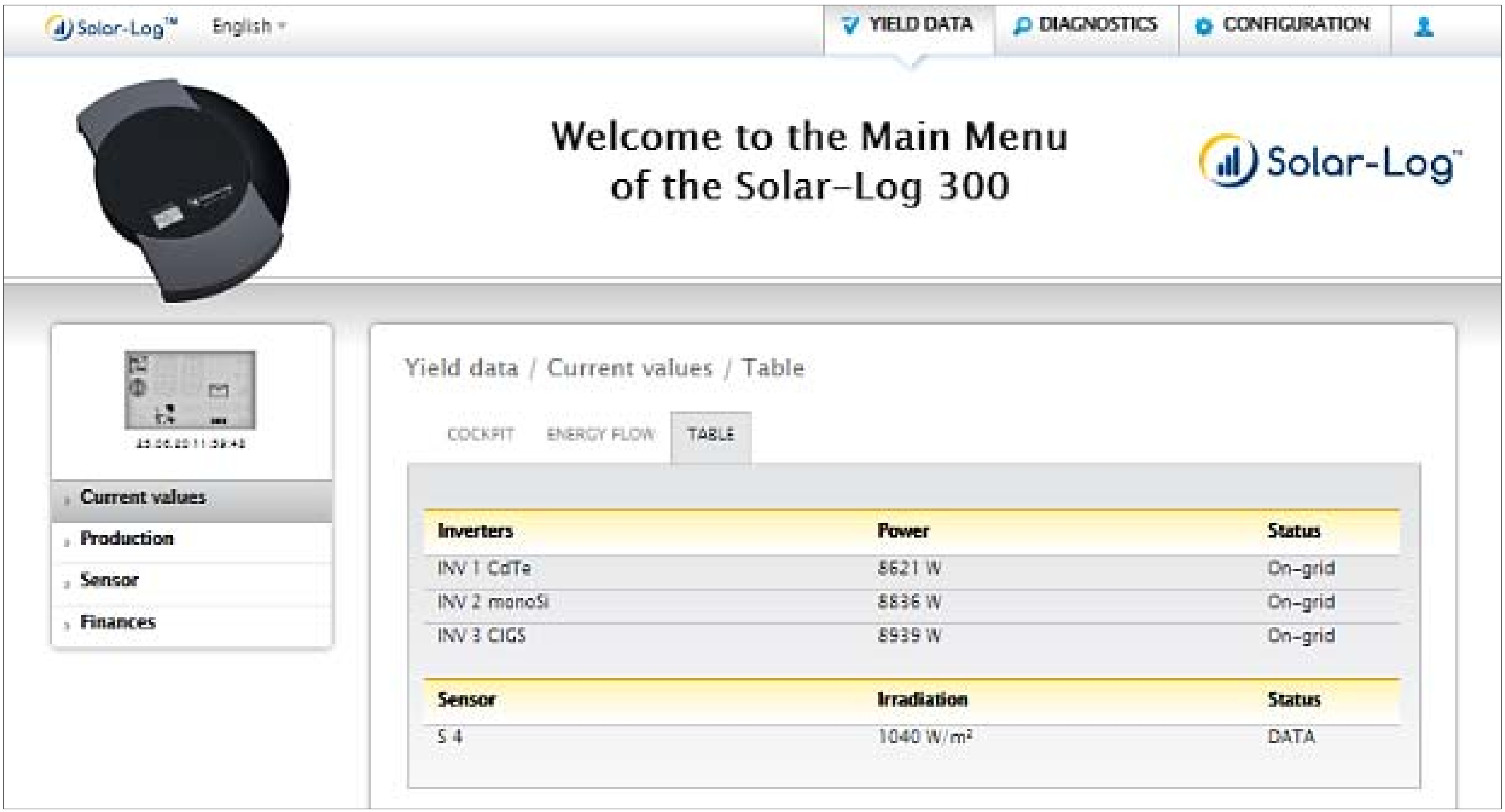
Direct communications with inverters SUN2000-10KTL-M0 over WiFi with FusionHome App





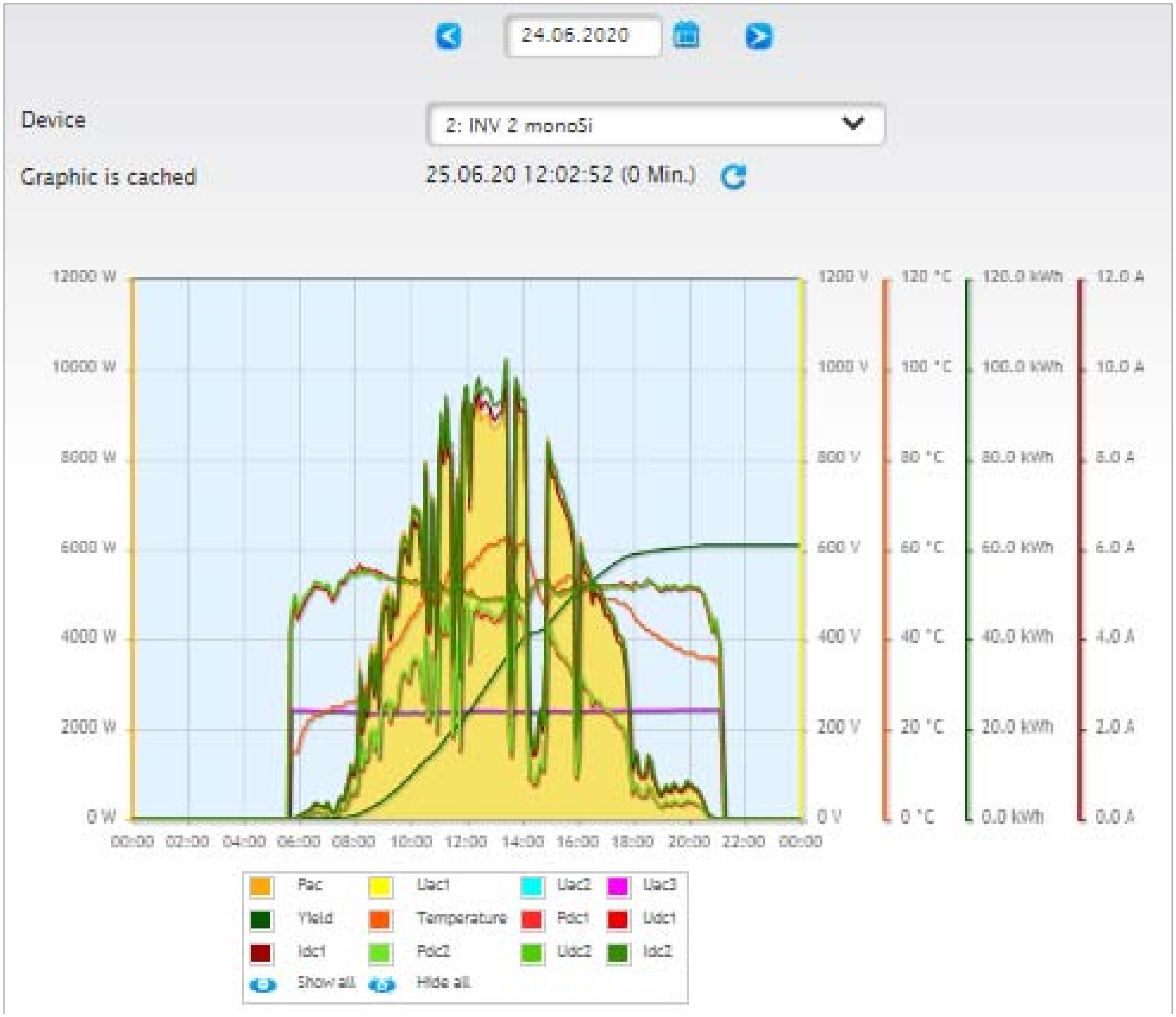
3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Solar-Log 300 – instantaneous values of AC power of the inverters of the three PV systems



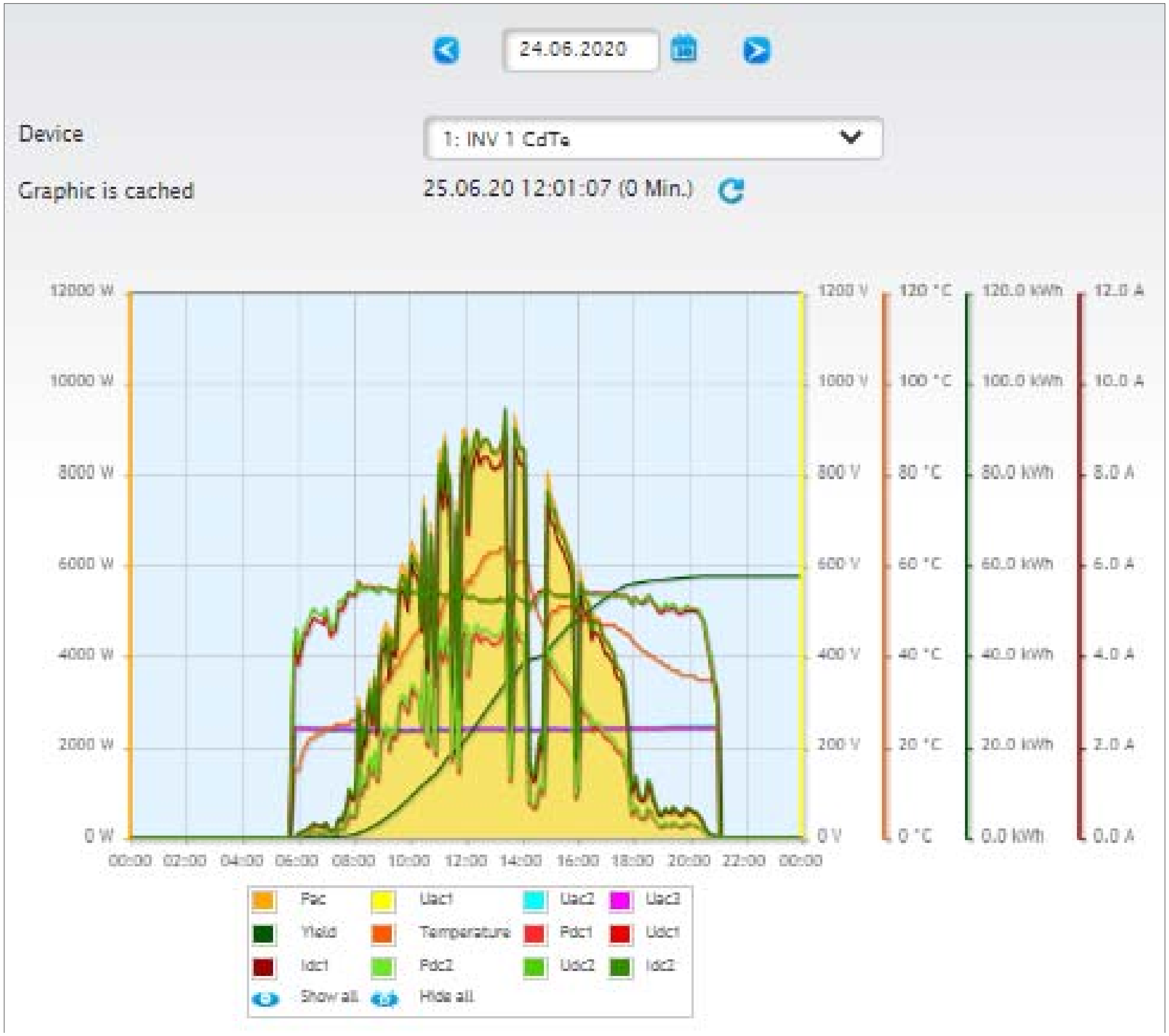
3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Solar-Log 300 – Inverter details of the mono-Si PV modules



3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Solar-Log 300 – Inverter details of the CdTe PV modules

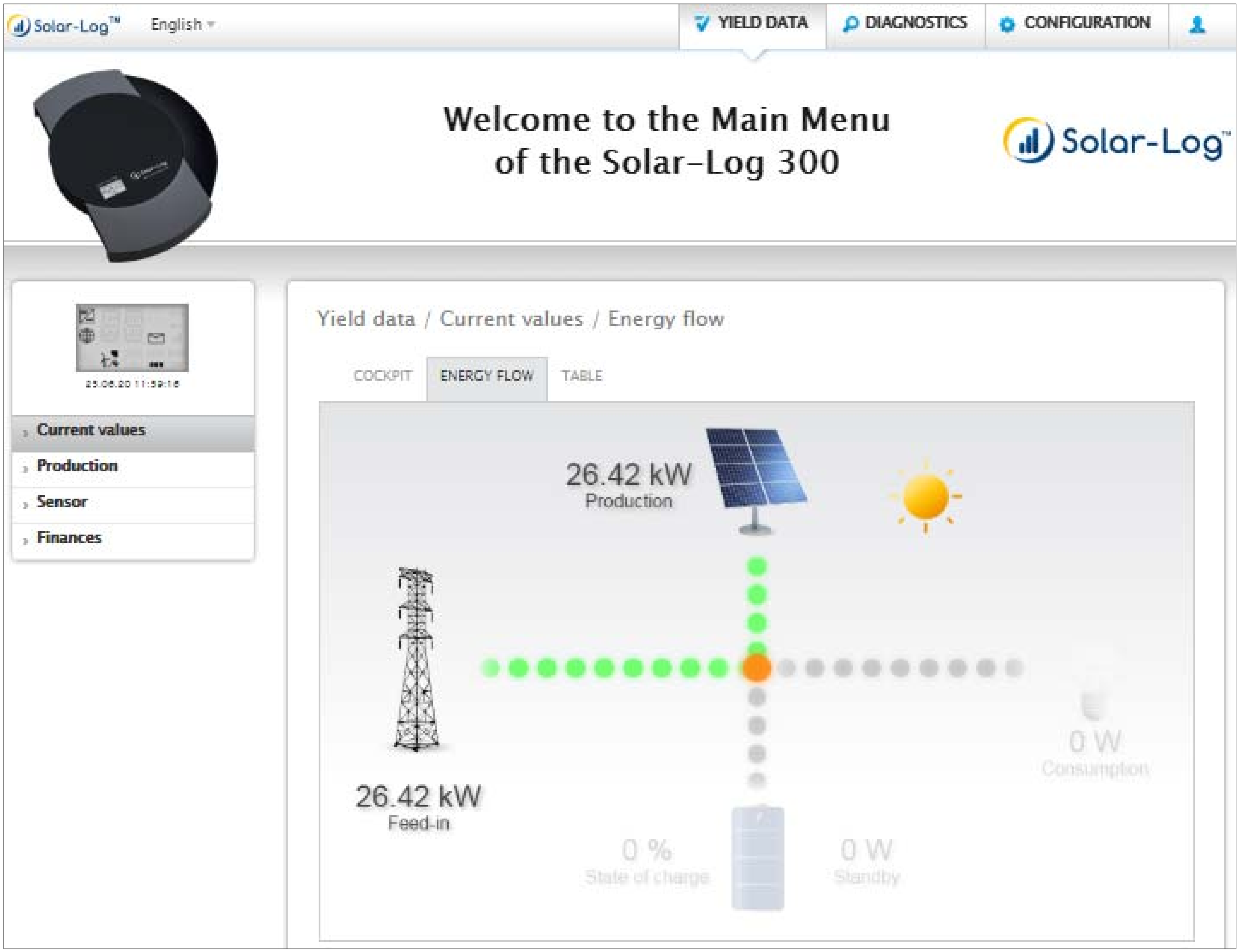


3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Solar-Log 300 – Inverter details of the CIGS PV modules

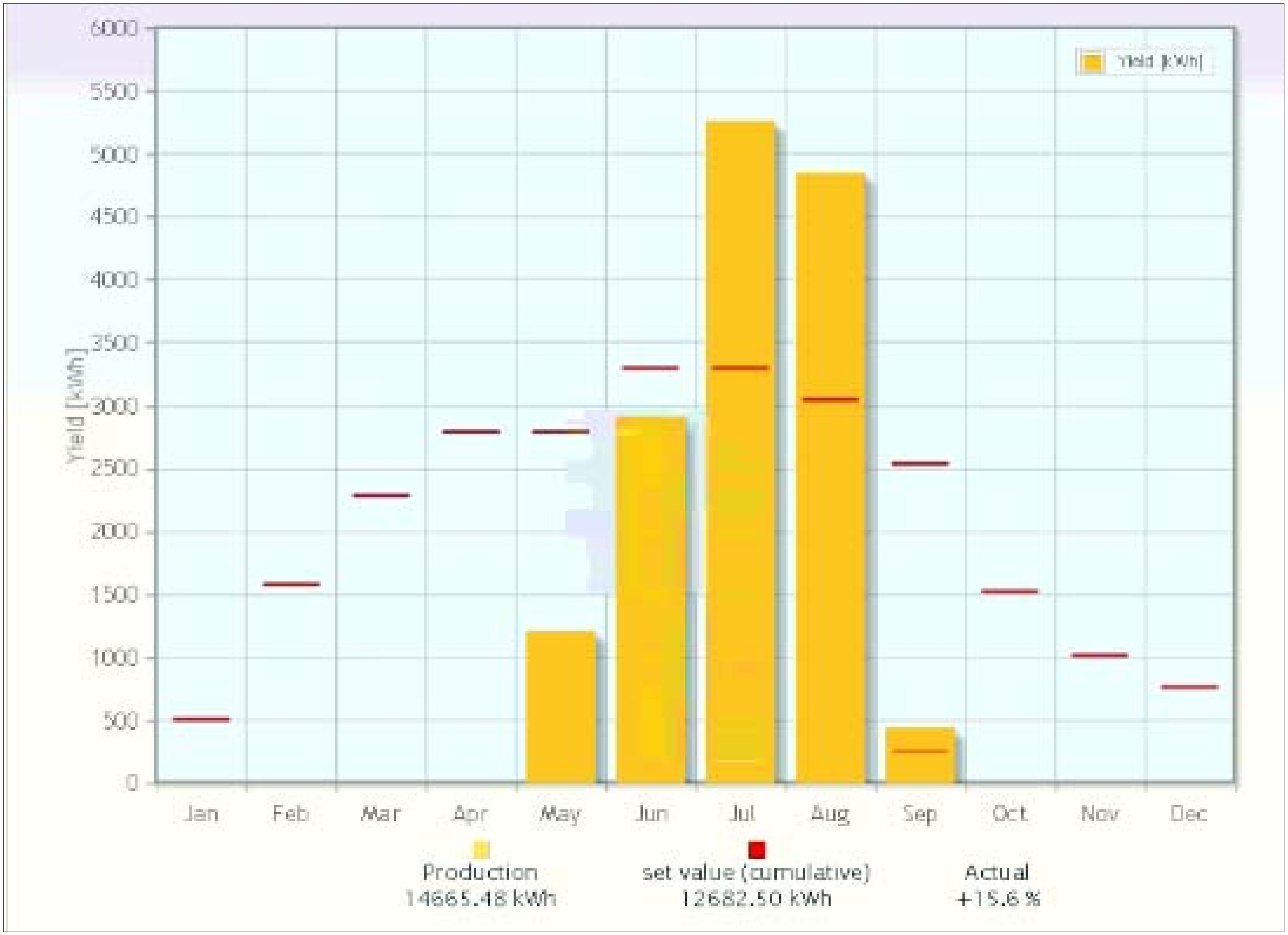
3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Solar-Log 300 – Monitoring of the energy flow



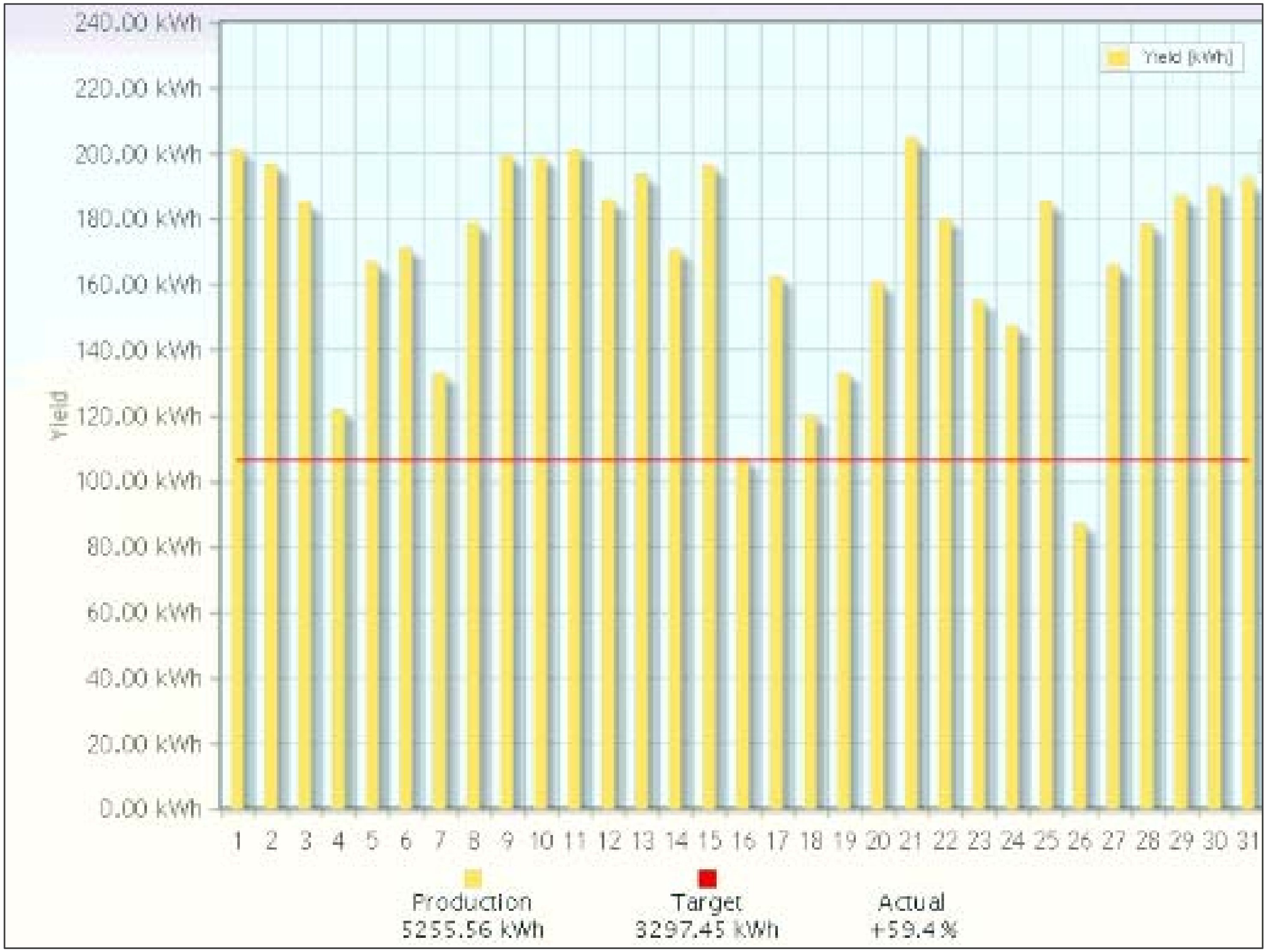
3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Solar-Log 300 – Production of electricity by months



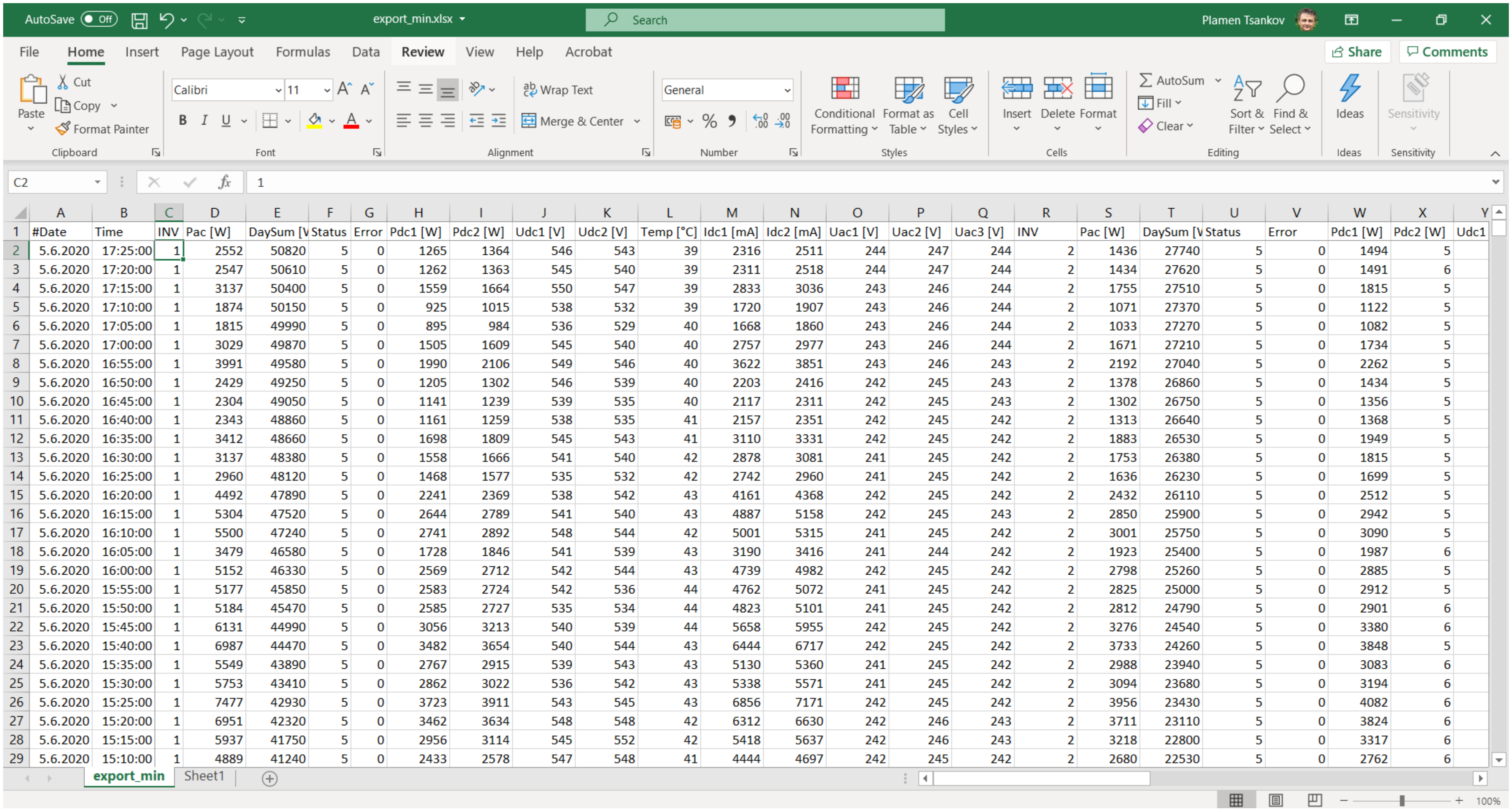
3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

Production of electricity in July 2020



3. INITIAL DATA FROM SOFTWARE FOR MONITORING OF METEOROLOGICAL AND ELECTRICAL PARAMETERS

All the monitored data is stored at every 5 minutes and can be exported as CSV file for additional more in-depth software analysis



1	#Date	Time	INV	Pac [W]	DaySum [V	Status	Error	Pdc1 [W]	Pdc2 [W]	Udc1 [V]	Udc2 [V]	Temp [°C]	Idc1 [mA]	Idc2 [mA]	Uac1 [V]	Uac2 [V]	Uac3 [V]	INV	Pac [W]	DaySum [V	Status	Error	Pdc1 [W]	Pdc2 [W]	Udc1
2	5.6.2020	17:25:00	1	2552	50820	5	0	1265	1364	546	543	39	2316	2511	244	247	244	2	1436	27740	5	0	1494	5	
3	5.6.2020	17:20:00	1	2547	50610	5	0	1262	1363	545	540	39	2311	2518	244	247	244	2	1434	27620	5	0	1491	6	
4	5.6.2020	17:15:00	1	3137	50400	5	0	1559	1664	550	547	39	2833	3036	243	246	244	2	1755	27510	5	0	1815	5	
5	5.6.2020	17:10:00	1	1874	50150	5	0	925	1015	538	532	39	1720	1907	243	246	244	2	1071	27370	5	0	1122	5	
6	5.6.2020	17:05:00	1	1815	49990	5	0	895	984	536	529	40	1668	1860	243	246	244	2	1033	27270	5	0	1082	5	
7	5.6.2020	17:00:00	1	3029	49870	5	0	1505	1609	545	540	40	2757	2977	243	246	244	2	1671	27210	5	0	1734	5	
8	5.6.2020	16:55:00	1	3991	49580	5	0	1990	2106	549	546	40	3622	3851	243	246	243	2	2192	27040	5	0	2262	5	
9	5.6.2020	16:50:00	1	2429	49250	5	0	1205	1302	546	539	40	2203	2416	242	245	243	2	1378	26860	5	0	1434	5	
10	5.6.2020	16:45:00	1	2304	49050	5	0	1141	1239	539	535	40	2117	2311	242	245	243	2	1302	26750	5	0	1356	5	
11	5.6.2020	16:40:00	1	2343	48860	5	0	1161	1259	538	535	41	2157	2351	242	245	242	2	1313	26640	5	0	1368	5	
12	5.6.2020	16:35:00	1	3412	48660	5	0	1698	1809	545	543	41	3110	3331	242	245	242	2	1883	26530	5	0	1949	5	
13	5.6.2020	16:30:00	1	3137	48380	5	0	1558	1666	541	540	42	2878	3081	241	245	242	2	1753	26380	5	0	1815	5	
14	5.6.2020	16:25:00	1	2960	48120	5	0	1468	1577	535	532	42	2742	2960	241	245	242	2	1636	26230	5	0	1699	5	
15	5.6.2020	16:20:00	1	4492	47890	5	0	2241	2369	538	542	43	4161	4368	242	245	242	2	2432	26110	5	0	2512	5	
16	5.6.2020	16:15:00	1	5304	47520	5	0	2644	2789	541	540	43	4887	5158	242	245	243	2	2850	25900	5	0	2942	5	
17	5.6.2020	16:10:00	1	5500	47240	5	0	2741	2892	548	544	42	5001	5315	241	245	242	2	3001	25750	5	0	3090	5	
18	5.6.2020	16:05:00	1	3479	46580	5	0	1728	1846	541	539	43	3190	3416	241	244	242	2	1923	25400	5	0	1987	6	
19	5.6.2020	16:00:00	1	5152	46330	5	0	2569	2712	542	544	43	4739	4982	242	245	242	2	2798	25260	5	0	2885	5	
20	5.6.2020	15:55:00	1	5177	45850	5	0	2583	2724	542	536	44	4762	5072	241	245	242	2	2825	25000	5	0	2912	5	
21	5.6.2020	15:50:00	1	5184	45470	5	0	2585	2727	535	534	44	4823	5101	241	245	242	2	2812	24790	5	0	2901	6	
22	5.6.2020	15:45:00	1	6131	44990	5	0	3056	3213	540	539	44	5658	5955	242	245	242	2	3276	24540	5	0	3380	6	
23	5.6.2020	15:40:00	1	6987	44470	5	0	3482	3654	540	544	43	6444	6717	242	245	242	2	3733	24260	5	0	3848	5	
24	5.6.2020	15:35:00	1	5549	43890	5	0	2767	2915	539	543	43	5130	5360	241	245	242	2	2988	23940	5	0	3083	6	
25	5.6.2020	15:30:00	1	5753	43410	5	0	2862	3022	536	542	43	5338	5571	241	245	242	2	3094	23680	5	0	3194	6	
26	5.6.2020	15:25:00	1	7477	42930	5	0	3723	3911	543	545	43	6856	7171	242	245	242	2	3956	23430	5	0	4082	6	
27	5.6.2020	15:20:00	1	6951	42320	5	0	3462	3634	548	548	42	6312	6630	242	246	243	2	3711	23110	5	0	3824	6	
28	5.6.2020	15:15:00	1	5937	41750	5	0	2956	3114	545	552	42	5418	5637	242	246	243	2	3218	22800	5	0	3317	6	
29	5.6.2020	15:10:00	1	4889	41240	5	0	2433	2578	547	548	41	4444	4697	242	245	242	2	2680	22530	5	0	2762	6	

export_min | Sheet1

4. ASSESSMENT OF THE ECOLOGICAL EQUIVALENT OF THE SAVED ENERGY IN BULGARIA

In Bulgaria, a mandatory state "Ordinance № E-RD-04-3 from 4.05.2016 on eligible measures for the implementation of energy savings in final consumption, ways of demonstrating the energy savings achieved, the requirements for their assessment methodologies and ways of confirmation" applies. A Specialized Commission on Electricity at the National Agency for Sustainable Energy Development, with the participation of the author of this publication, has developed a Methodology for estimating energy savings when installing photovoltaic systems, according to the Ordinance.

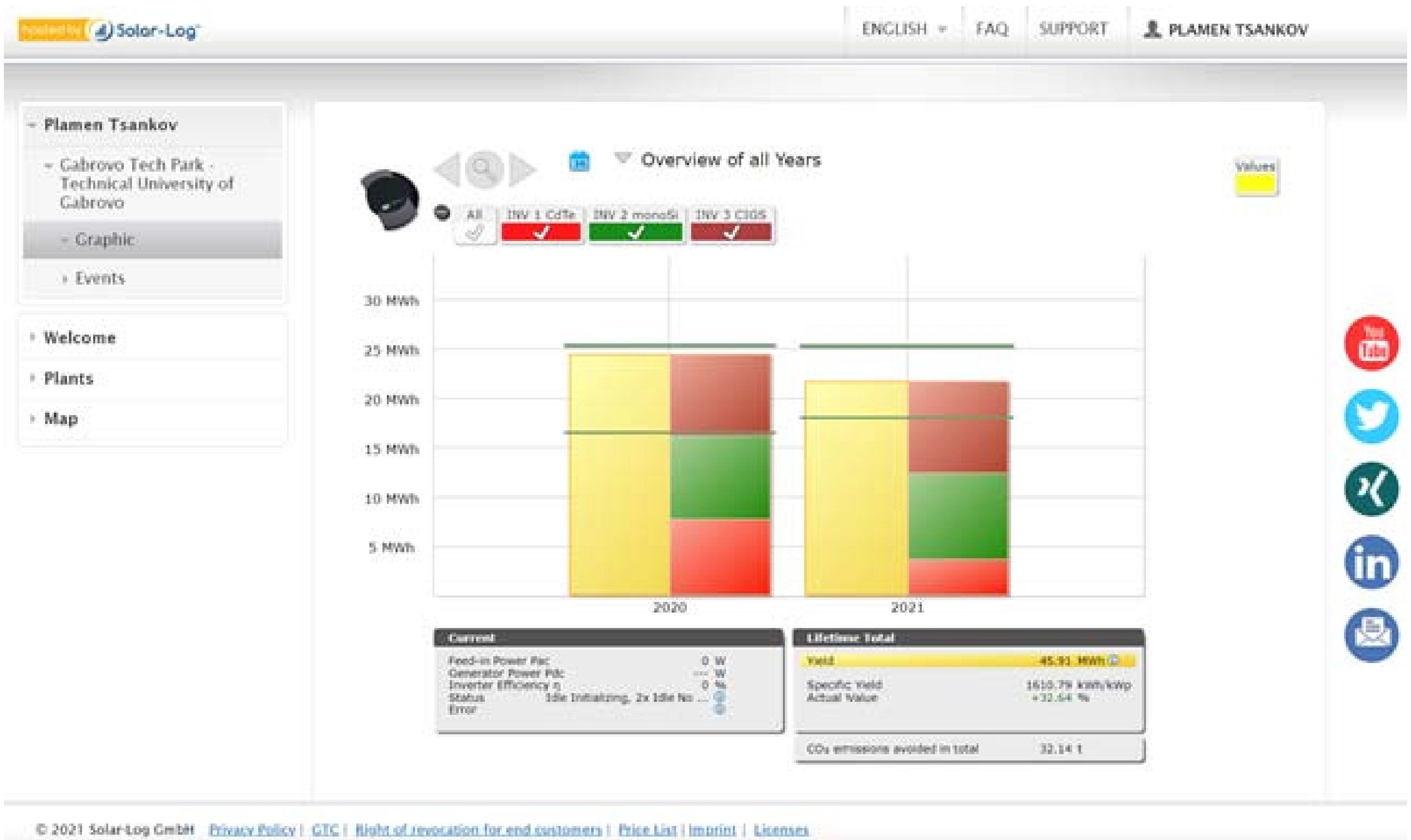
4. ASSESSMENT OF THE ECOLOGICAL EQUIVALENT OF THE SAVED ENERGY IN BULGARIA

Reference values of the conversion factor considering the losses for extraction / production and transmission of energy, including fuels, and Reference values of the coefficient of ecological equivalent of energy

Type of energy resource / energy	Conversion factor from FES to PES, considering energy losses	Ecological equivalent coefficient
	e_p	f_i
	[-]	[gCO_2/kWh]
Industrial gas oil, diesel	1.10	267
Fuel oil	1.10	279
Natural gas	1.10	202
Propane-butane	1.10	227
Black coal	1.20	341
Lignite / brown coal	1.20	364
Anthracite coal	1.20	354
Coal briquettes	1.25	351
Firewood, pellets	1.05	43
Heat from district heating	1.30	290
Electrical energy	3.00	819

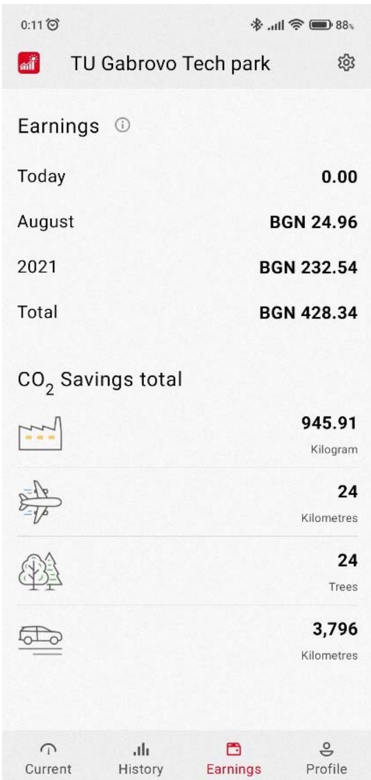
4. ASSESSMENT OF THE ECOLOGICAL EQUIVALENT OF THE SAVED ENERGY IN BULGARIA

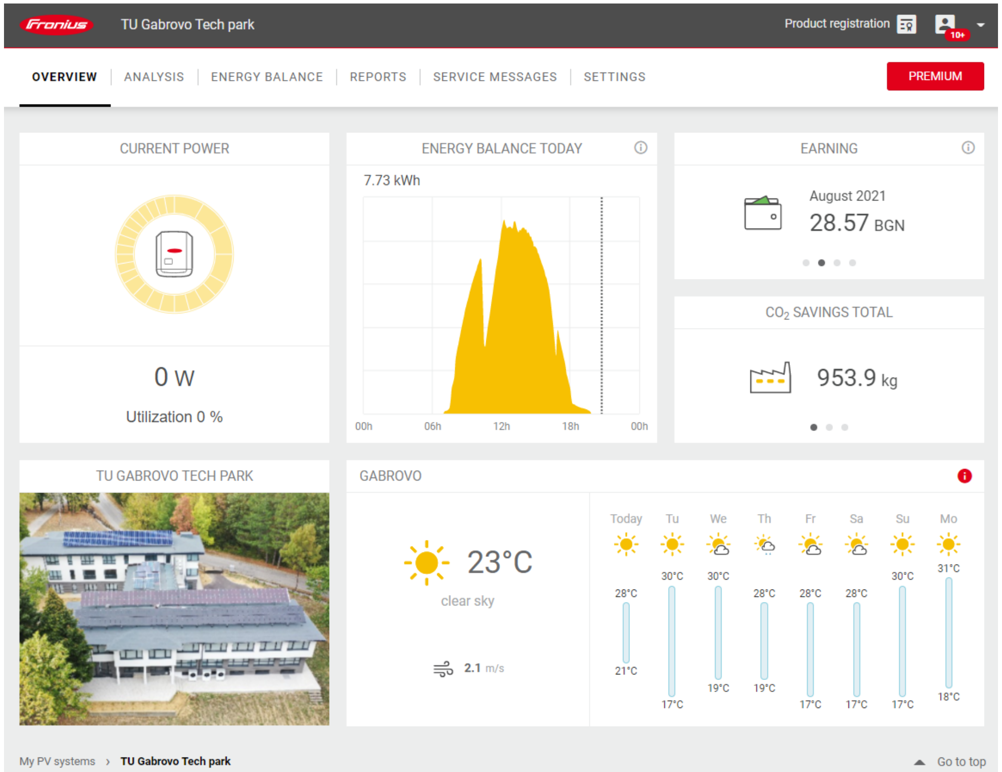
The analysis of the initial data from the monitoring systems of the new photovoltaic power plants in the Technology Park of the Technical University - Gabrovo, allows calculation of the necessary parameters for assessment of their impact on reducing carbon emissions and climate change. Web-view of the software for monitoring the 30 kWp (mono-Si, CdTe and CIGS) grid-connected power plants showing CO2 emissions avoided for the period from the launch of the power plant in May 2020 to July 2021, which are a total of 32.14 tons.



4. ASSESSMENT OF THE ECOLOGICAL EQUIVALENT OF THE SAVED ENERGY IN BULGARIA

The Android (left) and Web-based (right) software for monitoring the small hybrid PVT system (Fig. 2) are configured also to directly calculate the environmental benefits of its operation. The figures show an exemplary screenshots indicating the saved kilograms of CO2 emissions from the beginning of the system operation, as well as the corresponding number of saved trees or gained kilometers of movement of an airplane or a car with an internal combustion engine. The saved CO2 emissions for the period from the launch of the power plant in May 2020 to July 2021 are about 950 kilograms.





5. CONCLUSIONS

With the construction of the new three mono-Si, CdTe and CIGS power plants presented, together with the existing photovoltaic power plants with modules of a-Si and p-Si, 5 different photovoltaic materials can be tested simultaneously in the new laboratory at the Technology park of the Technical University of Gabrovo. The initial measured and stored comparative data from software for monitoring of meteorological and electrical operating parameters - solar radiation, temperature, wind speed, currents, voltages, and electrical power of each power plant, confirm the operability and functionality for future research of the new photovoltaic power plants constructed. Their modern systems for monitoring allow for a detailed analysis of the produced electricity and assessment of the impact on climate change of a similar type of widespread in Bulgaria roof-mounted PV power plants.

5. CONCLUSIONS

The carbon savings achieved by the small rooftop photovoltaic power plants in the present study are relatively small for major impacts on climate change but are useful with the ability to assess the savings potential of different photovoltaic module technologies. The considered technical solutions for roof PV power plants with a power of up to 30 kWp and their results are significant for the current stage of development of photovoltaic electricity in Bulgaria, as only for such power plants there is still FiT. A study in the register of newly built photovoltaic power plants in Bulgaria shows that in 2020, 759 new plants were built, of which 727, or 96% have a capacity of up to 30 kWp.

5. CONCLUSIONS

The technical solutions developed in this study and the results obtained can be useful for the correct choice of technology of photovoltaic modules and other elements of photovoltaic power plants, as well as for assessing their impact on climate change in Bulgaria and other countries or regions with similar weather conditions and profiles of energy sources in their electricity systems.

ACKNOWLEDGEMENT

This work was supported by the European Regional Development Fund within the OP "Science and Education for Smart Growth 2014 - 2020", Project CoC "Smart Mechatronic, Eco- And Energy Saving Systems And Technologies", № BG05M2OP001-1.002-0023.

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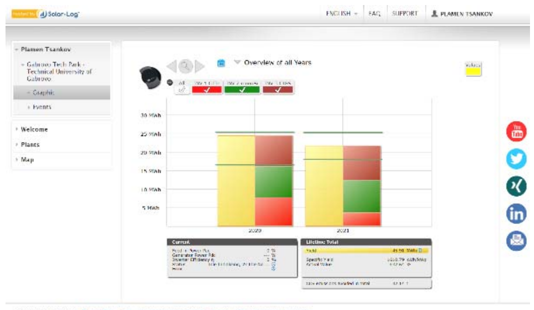
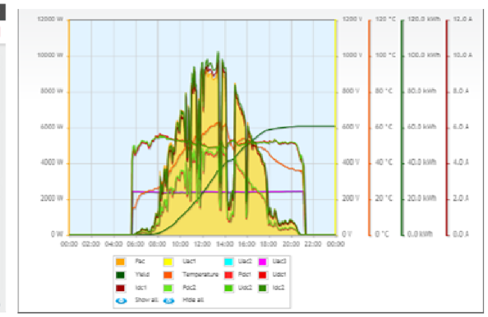
ACADEMY OF SCIENCES AND ARTS OF THE REPUBLIC OF SRPSKA

Влада Републике Српске

Министарство науке и технологије

THANK YOU FOR YOUR ATTENTION !





REDUCING CLIMATE CHANGE BY INSTALLING A NEW PHOTOVOLTAIC POWER PLANT IN BULGARIA

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