Comparison between Bifacial and Traditional Photovoltaic Modules in terms of I-V and P-V curves in different weather conditions

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***Abstract*— The performance of bifacial photovoltaic (bPV) modules and monofacial photovoltaic (mPV) modules under various operating conditions needs to be analyzed with research and development activities. This research work performed an experimental comparison of the energy performance of a bPV module and two mPV modules, based on experimental data measured at SolarTech^{LAB}, Department of Energy of the Politecnico di Milano, Italy. For this purpose, the performance ratio (PR) and the temperature- corrected PR proposed by the IEC 61724-1 standard for bPV and mPV modules were evaluated. To calculate the energy improvement of this technology over bi-directional amplification, measurements of south-facing ground-mounted PV modules were recorded over the lava bed from February 14 to February 18, 2023. Compared to the mPV module , the relative PR gain for bPV was 14.2% higher over the Sunpower monofacial module and a 23.9% higher over the Aleo monofacial module.**

Index Terms: PV, I-V curve, single-sided solar module, double-sided solar module Introduction.

I. Introduction

Society and governments are increasingly interested in green technologies. Governments in various countries promote environmental protection and renewable energy and pass laws to support and promote them. Among the most important initiatives are the 2030 Agenda[1]. This new form of energy opens up huge markets for clean technologies for international investment and competition. Photovoltaics (PV) can be considered as one of the most advanced and widespread renewable energy production systems that reduce the impact of climate change, which in turn affects PV performance [2]. According to a study by the International Energy Agency PV production will increase to a record 270 TWh (26% more) in 2022, reaching almost 1,300 TWh. In 2022, it recorded the largest absolute increase in production of any renewable energy technology, surpassing wind for the first time in history. This generational growth rate is in line with that projected for the 2023-2030 period in the 2050 Zero Emissions Scenario [3]. Bifacial modules capture sunlight from both sides of the module and therefore, compared to traditional single-sided photovoltaic (mPV) modules, have an efficiency of 6% to 10% [4]. SolarPower Europe expects the solar industry to experience remarkable growth in 2023: in its Medium Scenario, new installed solar capacity will reach 341 GW, reflecting a growth rate of 43% compared to 239 GW installed in 2022 [5]. Bilateral gain, defined as the ratio of the output power of a bPV module to the output power of an equivalent front-end only module, is commonly used for such comparisons [6].

Reference review. [7] and [8] it can be concluded that: (i) bPV modules tend to run cooler than single-sided modules; (ii) when the back radiation is particularly high, the bPV module can become warm, but (iii) even then, the energy gained from the bPV reaction exceeds the energy lost due to the higher temperature.

Another important variable is the height of the bPV module from the ground, which also affects the power output as the back radiation changes [9]. The climate conditions has a direct impact on the efficiency of PV modules. Compared to mPV, the bPV module has a bigger sense to changes of weather and climate conditions as the bPV has two sides of solar cells and a bigger area.

The comparison of mPV and bPV modules based on I-V (current-voltage) and P-V (power-voltage) curves are obtained through a matlab simulation .It is of fundamental importance to prior knowledge of the power of photovoltaic modules under various weather conditions. To fully define the IV and PV characteristics of a bPV module under standard test conditions (STC), it is necessary to expand the STC definition to include the complete spectrum distribution and backlighting of the PV module. Typically, the characteristics of an indoor PV module allow the most precise control of these values. In addition, a comparison of single and double-sided lighting was performed. To contribute to the development of this study, this work aims to investigate energy efficiency and other parameters behavior mPV and bPV modules in different weather and operating conditions.

Specifically, the goals are: Determine the power production of the threh modules for different values of solar irradiance and photocell temperature, emphasizing their importance and impact. Changes in these operating parameters are obtained by measuring the CVC on different days and intervals. Also other variables comparison of the same modules as Voc, Isc, Pmpp, Vmpp, Impp. In all operating modes, analysis of key parameters such as short-circuit current and open-circuit voltage was performed.

Solar irradiance, temperature and AC were measured for each configuration and at a constant 30° inclination to evaluate the array's performance under the same environmental conditions for 3 different days with different climate conditions. Part II describes the methodology used and describes the experimental setup and case studies, and Part III presents the results of the trials along with an extensive discussion of them. Finally, section IV outlines the main findings of this paper and the conclusión.

II. MATERIALS AND METHODS

The aim of this study was to collect and analyze IV and PV curves that characterize the activity and efficiency of bPV modules at different time points and under different operating conditions, namely (i) different bPV and mPV profiles and (ii) different slopes, dates and time periods, giving different irradiance results. and photoelectric temperature values. Specifically, the bPV modules are housed in the SolarTech^{LAB} laboratory in Milan (45.50° N; 9.16° E), located on the roof of the building of the Energy Department of the Politecnico di Milano. SolarTech^{LAB} diagram and cheap tools have been designed and improved for many years to measure the performance of photovoltaic systems integrated with external shading devices [10] to evaluate the performance of the performance. Solar energy under the actual conditions of external conditions [11], [12], Provide practical data to evaluate between different prognosis methods (specific models and hybrids based on artificial nerve network) for actual output power [13]. The angle of the solar frequency on the surface of the BPV and MPV tissue is constant at 30º tilt structure, allowing the BPV to be rotated only along the horizontal axis. The azimuth angle of the structure is -6 ° (provided that 0 ° is noon and the angle to the west). In this way, in addition to the change of solar irradiance before and after the bPV module. Experimental campaigns were performed under sunny days and cludy days to collect data of different levels of irradiance.

A. *Bifacial and monofacial PV characteristics and working conditions*

The PV module taken into consideration is a SPR-E20-327 manufactured by SunPower® E-Series Residential Solar Panels | E20-327. Its main ratings are reported in Table I.

TABLE I: mPV module ratings in STC-SUNPOWER

Dimensions	1558 x 1046 mm	Cell number	96
I_{sc}	6.46 A	I_{sc} temp. coeff.	2.6 mA / o C
V_{oc}	64.9 V	V_{oc} temp. coeff.	–176.6 mV / o C
P_{mpp}	327 W	P_{mpp} temp. coeff.	–0.35% / o C
V_{mpp}	54.7 V	Efficiency	18.56%
I_{mpp}	5.98 A	NOCT	*49°C*

Fig. 1: SUNPOWER monofacial module

The PV module taken into consideration is a Aleo Solar S79Y305 (305W) manufactured by Aleo Solar. Its main ratings are reported in Table II.

TABLE II: mPV module ratings in STC-ALEO

Dimensions	1.660 x 990 mm	Cell number	60
I_{sc}	8.15 A	I_{sc} temp. coeff.	0.05%/K
V_{oc}	36.4V	V_{oc} temp. coeff.	-0,106V/K
P_{mpp}	305 W	P_{mpp} temp. coeff.	-0.4%/K
V_{mpp}	28.5V	Efficiency	18.56%
I_{mpp}	7.86A	Bifaciality factor	*49°C*

Fig. 2: ALEO monofacial module

The PV module taken into consideration is a 3S DUAL 72N model (3SBA345A) manufactured by Enel Green Power[1]. Its main ratings are reported in Table I.

TABLE III: bPV module ratings in STC

Dimensions	1983 x 998 mm	Cell number	72
I_{sc}	9.18 A	I_{sc} temp. coeff.	+0.048 %/°*C*
V_{oc}	47.9 V	V_{oc} temp. coeff.	-0.3 %/°*C*
P_{mpp}	345 W	P_{mpp} temp. coeff.	-0.38 %/°*C*
V_{mpp}	39.3 V	Efficiency	17.4 %
I_{mpp}	8.78 A	Bifaciality factor	>85 %

Fig. 3: Bifacial module

III RESULTS

TABLE IV: 1st campaign: irradiance components, cell temperature and main electrical parameters of SUNPOWER panel.

DAY 14th	Pmpp1 (W)	G_dirF1 (W/m2)	G_difF1 (W/m2)	G_rifF1 (W/m2)	G_totF1 (W/m2)	Impp1 (A)	Vmpp1 (V)	Isc1 (A)	Voc1 (V)	Temp Cell (C°)
1.1	198.27	680.74	76.51	2.57	759.82	3.88	51.11	4.02	61.96	34.76
1.2	225.10	763.26	78.37	3.03	844.66	4.41	51.00	4.65	61.42	37.48
1.3	238.45	799.94	78.37	3.27	881.59	4.71	50.58	5.01	61.10	40.93
1.4	245.49	810.78	78.37	3.39	892.55	4.84	50.68	5.17	60.99	41.19
1.5	246.99	801.62	76.22	3.44	881.28	4.87	50.68	5.24	60.99	42.79
1.6	201.91	619.95	67.18	2.77	689.89	3.99	50.58	4.21	60.88	39.53
1.7	201.91	619.95	67.18	2.77	689.89	3.99	50.58	4.21	60.88	39.53
1.8	247.61	808.06	77.44	3.43	888.94	4.88	50.79	5.23	60.99	41.78
1.9	150.02	435.49	55.05	1.98	492.52	2.92	51.33	3.08	60.99	35.52
1.10	117.05	321.30	46.65	1.49	369.44	2.23	52.51	2.35	60.13	33.30
4.1	180.63	588.92	91.44	2.38	682.73	3.47	52.08	3.65	61.64	34.47
4.2	209.10	674.39	106.36	2.93	783.68	4.13	50.58	4.34	60.99	41.79
4.3	214.88	591.09	113.10	2.87	707.06	4.18	51.43	4.42	61.53	38.84
4.4	134.59	344.39	149.97	2.29	496.65	2.65	50.79	2.75	60.24	39.45
4.5	254.97	749.86	108.23	3.54	861.63	4.96	51.43	5.22	62.28	37.24
4.6	183.89	392.83	94.95	2.14	489.91	3.48	52.83	3.67	62.49	32.31
5.1	91.30	85.70	209.60	1.75	297.04	1.74	52.51	1.80	52.94	27.65
5.2	148.10	204.34	222.20	2.29	428.84	2.81	52.62	2.94	62.17	28.65
5.3	160.97	274.33	238.85	2.68	515.86	3.06	52.62	3.23	61.96	31.32
5.4	148.01	241.63	236.28	2.53	480.45	2.85	51.97	3.03	60.99	36.39
5.5	131.80	211.72	222.06	2.32	436.10	2.57	51.33	2.69	60.67	36.84
5.6	119.50	186.09	211.79	2.15	400.04	2.31	51.65	2.43	60.24	36.00
5.7	103.51	158.94	185.05	1.87	345.86	1.97	52.51	2.06	57.55	33.34

TABLE V: 2st campaign: irradiance components, cell temperature and main electrical parameters of ALEO panel.

DAY 17th	Pmpp2 (W)	G_dirF2 (W/m2)	G_difF2 (W/m2)	G_rifF2 (W/m2)	G_totF2 (W/m2)	Impp2 (A)	Vmpp2 (V)	Isc2 (A)	Voc2 (V)	Temp Cell (C°)
1.1	183.66	691.85	76.54	2.63	771.01	5.98	30.71	6.20	37.26	33.67
1.2	209.19	772.45	78.37	3.07	853.89	6.91	30.28	7.23	36.94	37.11
1.3	219.70	799.14	78.37	3.28	880.79	7.33	29.96	7.60	36.72	38.86
1.4	226.30	811.42	78.37	3.40	893.19	7.58	29.85	7.95	36.62	41.60
1.5	227.52	809.17	77.44	3.44	890.05	7.59	29.96	8.01	36.62	42.17
1.6	227.51	798.19	76.51	3.43	878.12	7.65	29.74	8.00	36.62	40.77
1.7	183.51	620.82	67.18	2.77	690.77	6.08	30.17	6.32	36.83	37.13
1.8	227.52	809.17	77.44	3.44	890.05	7.59	29.96	8.01	36.62	42.17
1.9	135.39	428.82	55.05	1.96	485.83	4.42	30.60	4.58	36.94	33.04
1.10	103.85	318.14	46.65	1.47	366.27	3.29	31.57	3.45	37.26	31.03
4.1	163.81	589.04	90.50	2.38	681.92	5.28	31.03	5.43	37.26	31.52
4.2	209.10	674.39	106.36	2.93	783.68	4.13	50.58	4.34	60.99	35.86
4.3	224.45	680.31	117.77	3.22	801.30	7.44	30.17	7.65	37.26	36.11
4.4	103.66	275.75	129.70	1.90	407.34	3.36	30.82	3.48	36.51	35.56
4.5	230.97	739.93	108.23	3.50	851.66	7.63	30.28	7.80	37.37	36.11
4.6	181.17	545.00	113.83	2.84	661.68	5.74	31.57	5.96	37.69	31.10
5.1	84.89	66.47	205.26	1.64	273.37	2.68	31.68	2.74	37.05	28.25
5.2	147.02	263.43	232.95	2.60	498.98	4.64	31.68	4.77	37.69	29.38
5.3	140.31	258.87	238.85	2.62	500.34	4.44	31.57	4.60	37.37	31.63
5.4	129.73	236.39	225.81	2.44	464.65	4.24	30.60	4.37	36.72	35.84
5.5	119.71	207.21	222.99	2.31	432.51	3.88	30.82	4.00	36.72	34.96
5.6	113.38	190.52	210.59	2.16	403.27	3.67	30.93	3.79	36.83	34.73
5.7	94.22	157.34	182.00	1.84	341.18	2.98	31.57	3.07	36.94	31.90

TABLE VI: 3^{st} campaign: irradiance components, cell temperature and main electrical parameters of Bifacial panel.

DAY 18th	Pmpp3 (W)	G_dirF3 (W/m2)	G_difF3 (W/m2)	G_rifF3 (W/m2)	G_totF3 (W/m2)	G_difR3 (W/m2)	G_rifR3 (W/m2)	G_totR3 (W/m2)	Impp3 (A)	Vmpp3 (V)	Isc3 (A)	Voc3 (V)	Temp Cell (Cº)
1.1	233.68	695.91	77.44	2.66	776.01	5.56	36.99	42.55	5.98	37.37	6.58	45.31	33.22
1.2	259.96	769.18	78.10	3.06	850.34	5.61	42.66	48.27	6.91	37.26	7.45	45.10	36.37
1.3	272.37	800.25	78.37	3.28	881.91	5.63	45.75	51.37	7.33	36.62	7.87	44.88	38.25
1.4	279.40	809.10	78.59	3.39	891.08	5.64	47.27	52.91	7.58	36.19	8.18	44.56	41.65
1.5	282.82	804.43	77.44	3.43	885.29	5.56	47.73	53.29	7.59	36.29	8.31	44.67	42.18
1.6	230.56	613.94	67.18	2.75	683.86	4.82	38.28	43.10	7.65	37.26	6.57	44.88	37.79
1.7	230.56	613.94	67.18	2.75	683.86	4.82	38.28	43.10	6.08	37.26	6.57	44.88	37.79
1.8	282.82	804.43	77.44	3.43	885.29	5.56	47.73	53.29	7.59	36.29	8.31	44.67	42.18
1.9	172.87	425.75	55.05	1.95	482.74	3.95	27.10	31.05	4.42	37.69	4.75	44.99	34.09
1.10	132.38	309.67	46.65	1.44	357.76	3.35	20.08	23.43	3.29	38.12	3.56	45.10	31.87
4.1	207.91	583.22	90.70	2.37	676.29	6.51	32.96	39.47	5.28	37.58	5.77	45.31	27.65
4.2	230.07	641.92	104.50	2.82	749.24	7.50	39.26	46.76	4.13	36.29	6.57	44.56	36.42
4.3	274.67	705.71	118.49	3.32	827.52	8.51	46.25	54.75	7.44	37.26	7.80	45.21	35.98
4.4	90.37	178.15	108.19	1.39	287.73	7.77	19.41	27.18	3.36	37.37	2.50	43.70	34.74
4.5	286.75	729.39	108.23	3.47	841.09	7.77	48.29	56.06	7.63	37.48	8.09	45.53	34.27
4.6	244.80	566.24	117.39	2.95	686.58	8.43	41.07	49.50	5.74	37.69	6.73	45.64	32.56
5.1	111.39	78.66	206.20	1.70	286.56	14.80	23.64	38.45	2.68	39.41	2.92	45.21	27.67
5.2	192.88	278.02	235.12	2.67	515.81	16.88	37.16	54.04	4.64	38.44	5.15	45.85	28.98
5.3	181.75	244.48	235.39	2.54	482.41	16.90	35.37	52.27	4.44	38.01	4.90	45.42	30.70
5.4	165.21	237.35	222.06	2.42	461.83	15.94	33.73	49.67	4.24	37.48	4.52	44.88	34.52
5.5	154.52	204.50	222.99	2.30	429.79	16.01	32.04	48.05	3.88	38.01	4.22	44.88	34.74
5.6	154.52	204.50	222.99	2.30	429.79	16.01	32.04	48.05	3.67	38.01	4.22	44.88	34.74
5.7	132.63	159.00	181.94	1.85	342.78	13.06	25.70	38.76	2.98	38.33	3.51	45.10	32.76

The test campaigns were performed in 3 different days specifically 14^{th}, 17^{th} and 18^{th} of February of 2023 looking for different radiation levels and changing climate conditions.

This are the values of Maximum Power Point (W), Direct and Total radiation (W/m^2), Current at Maximum Power Point (A), Voltage at Maximum Power Point (V), Short-Circuit Current (A), Open-Circuit Voltage (V) and the temperatureof the Photovolthaic cell for the 3 different days. There are five attempts inside each one of the 10 tests for the first day, 7 tests for the second day and 6 tests for the third day that are showed in this table , we chose the representative one of the five tests.

The big difference of irradiance in the same day for example in the tests 8 an 9 of the first day G_direct_8 = 808.06 W/m^2, G_total_8 = 888.94 W/m^2, G_direct_9 = 435.49 W/m^2, G_total_9 = 492.52 W/m^2, are caused by a big cloud that block the solar irradiance the solar panels receive.

To get the I-V and P-V curves for different solar radiations and climate conditions was used a Matlab code, the irradiance data and main electrical parameters are reported in the Tables IV, V and VI.

Concerning the three campaigns , characterized by low, medium and high levels of irradiance, the same qualitative results of the 1^{st}, 2^{nd} and 3^{rd} campaign have been found, as reported in Table IV, V, VI.

The differences are only quantitatively, and they can be summarized as follows:

- The power at the maximum power point is maximized with values of 254.97 W for Sunpower panel, 230.97 W for ALEO panel and 286.75 W for Bifacial panel, generating a 12% and a 24% more power tan the other two modules at the fifth test in the second campaign of tests.
- Bifacial panel for a radiation of 861.63 W/m^2 for Sunpower, 851.66 W/m^{2}for Aleo, 841.09 W/m^2 at the front and 56.06 G/m^2 for front and back for the Bifacial panel which are not the maximum values of solar radiation 892.55 W/m^2, 893.19 W/m^2, 891.08 W/m^2 and 52.91 G/m^2 for front and rear side this is because the solar panel has a specific efficiency and produces more power with a bit less of radiation.
- The lower maximum power corresponds to a radiation 91.30 W/m^2 for Sunpower panel, 84.89 W/m^2 for Aleo panel , 111.39 W/m^2 for Bifacial panel. In this configuration the solar irradiance on the front are 297.04 W/m^2 273.37 W/m^2 and for the front side of the bifacial panel 286.56 W/m^2 and for the rear side 38.45 W/m^2.
- The generated power increases when the solar irradiance increases but until a certain point because if the irradiance is maximum the efficiency of the solar panel decreases and the power generation decreases too. With a total radiation of 689.89 W/m^2 , 690.77 W/m^2 , 683.86 W/m^2 front and 43.10 W/m^2 at the rear side, generating respectively Sunpower 201.91 W,

Aleo 183.51 W, Bifacial 230.56 W The maximum power is generated by the bifacial panel because has a bigger area of panel and has two sides front and back, so receives more irradiance , generates 25.6% more powewr compared with the panel that less generates which is the Aleo panel, the second panel that generates more power is the Sunpower panel which with a similar area than the Aleo panel and produces a 10% more than the Aleo panel.

- The cell temperature is higher for high irradiance values and it ranges between 27.6 °C and 41.8 °C. This result is mainly correlated with the irradiance for higher cell temperature less efficiency.
- The values of I_{sc} of Aleo and Bifacial are almost the same, instead Sunpower values are 52.7% than the values of the other two solar panels. However the maximum U_{oc} value is from the Sunpower panel being 66% higher than Aleo panel and 36.4% higher than Bifacial panel.
- The second and fourth test of the 2^{th} campaign are declined because generated some values that are strange in terms of tension, intensity and power.

A. *First experimental campaign graphs*

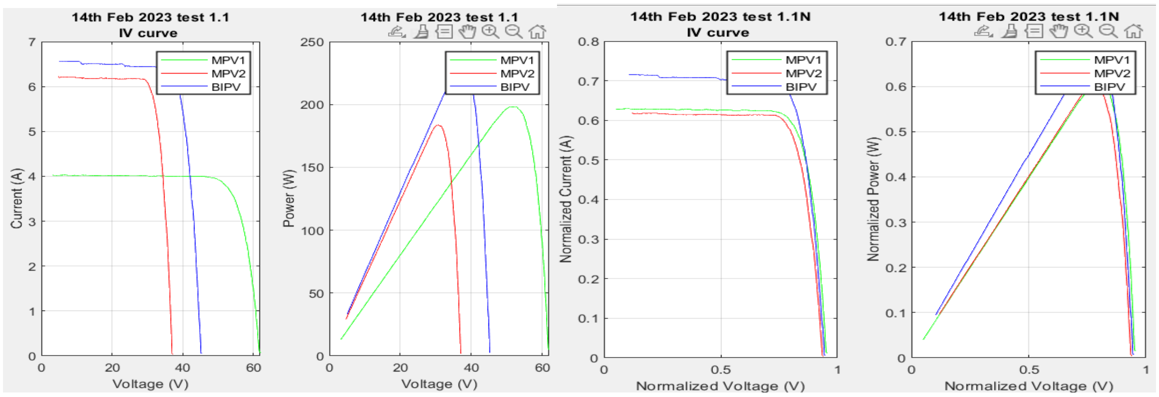

Fig. 4: I-V and P-V curves normalized and non-normalized of the test 1 day 1.

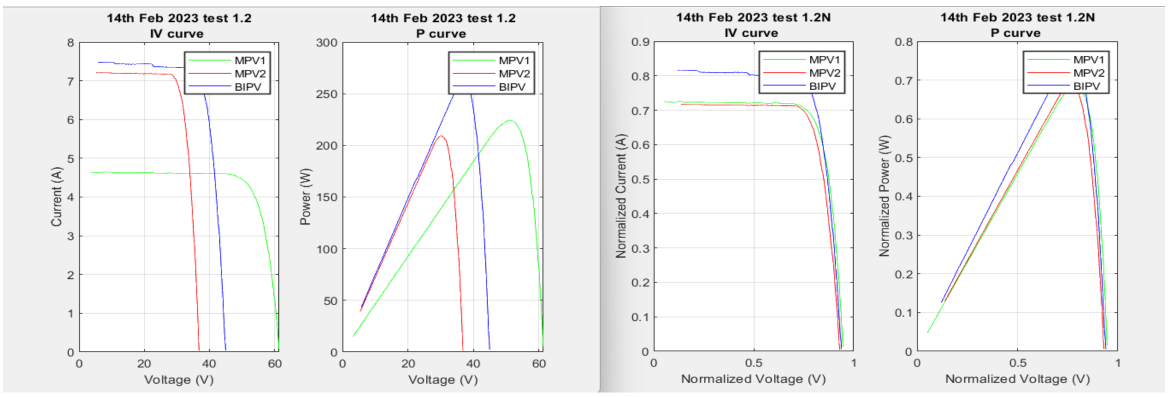

Fig. 5: I-V and P-V curves normalized and non-normalized of the test 2 day 1.

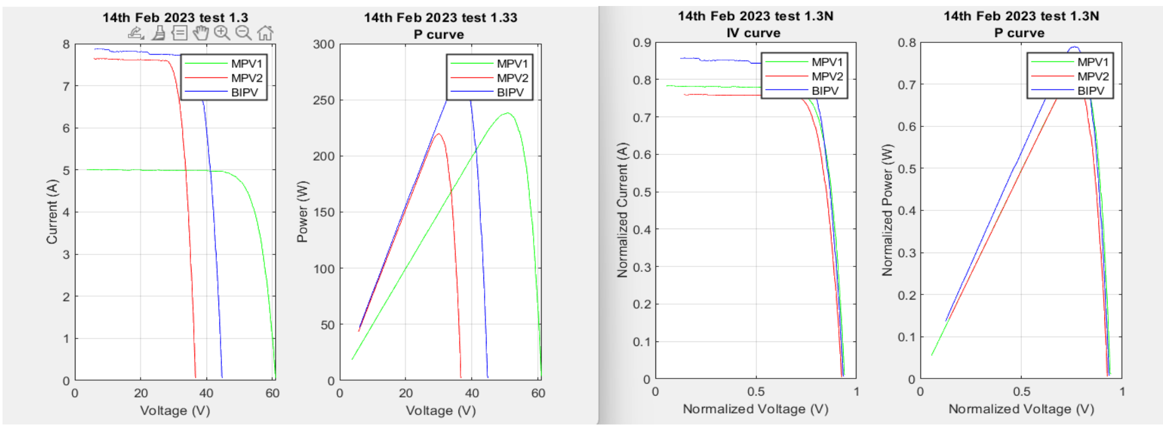

Fig. 6: I-V and P-V curves normalized and non-normalized of the test 3 day 1.

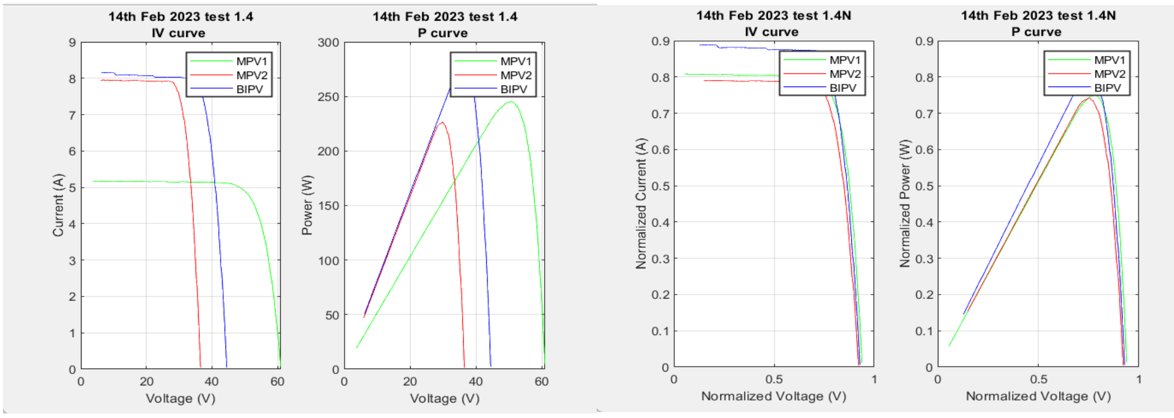

Fig. 7: I-V and P-V curves normalized and non-normalized of the test 4 day 1.

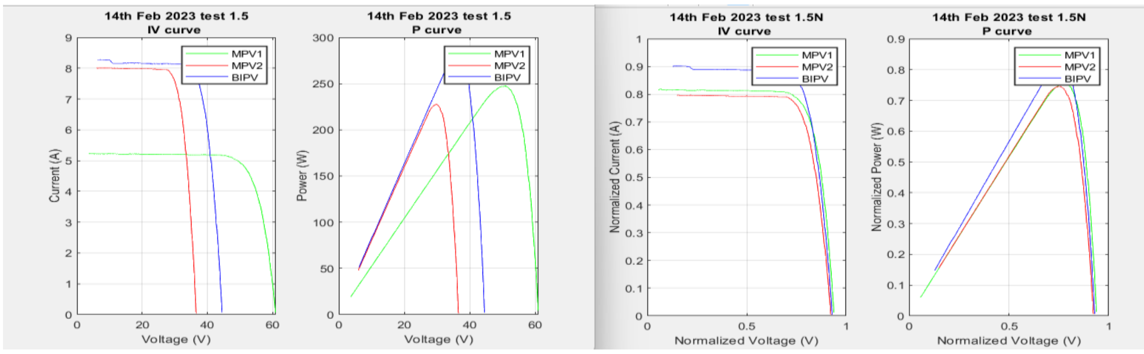

Fig. 8: I-V and P-V curves normalized and non-normalized of the test 5 day 1.

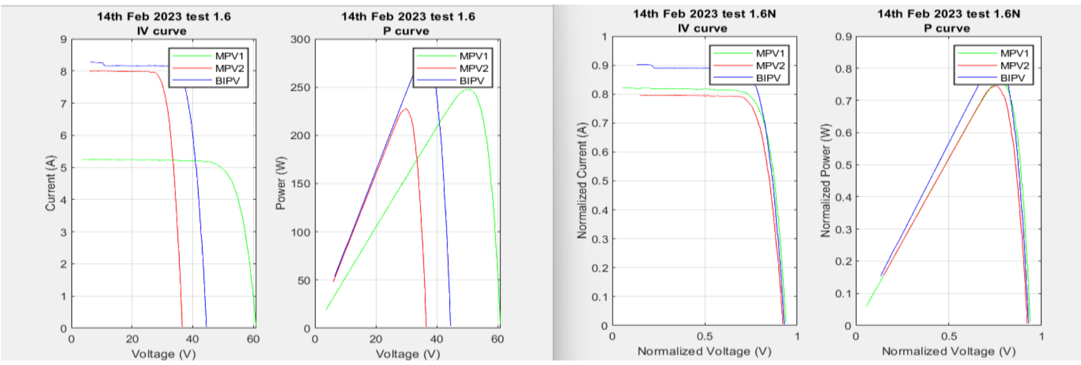

Fig. 9: I-V and P-V curves normalized and non-normalized of the test 6 day 1.

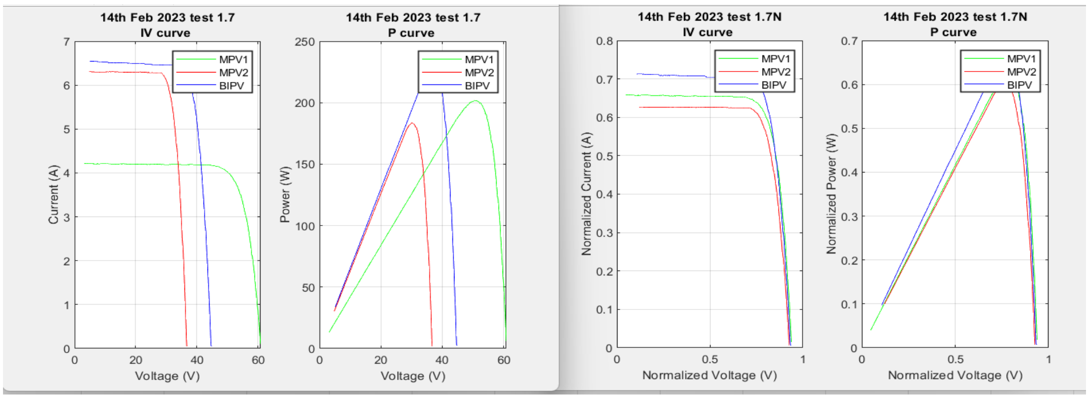

Fig. 10: I-V and P-V curves normalized and non-normalized of the test 7 day 1.

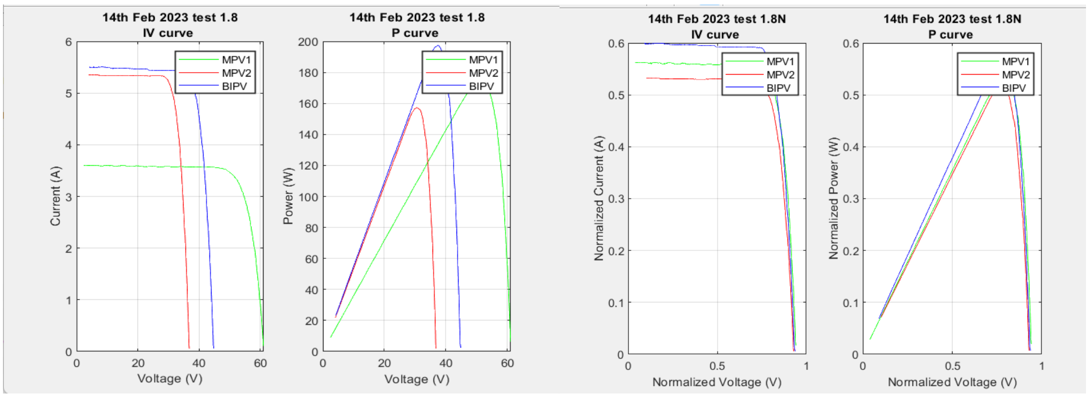

Fig. 11: I-V and P-V curves normalized and non-normalized of the test 8 day 1.

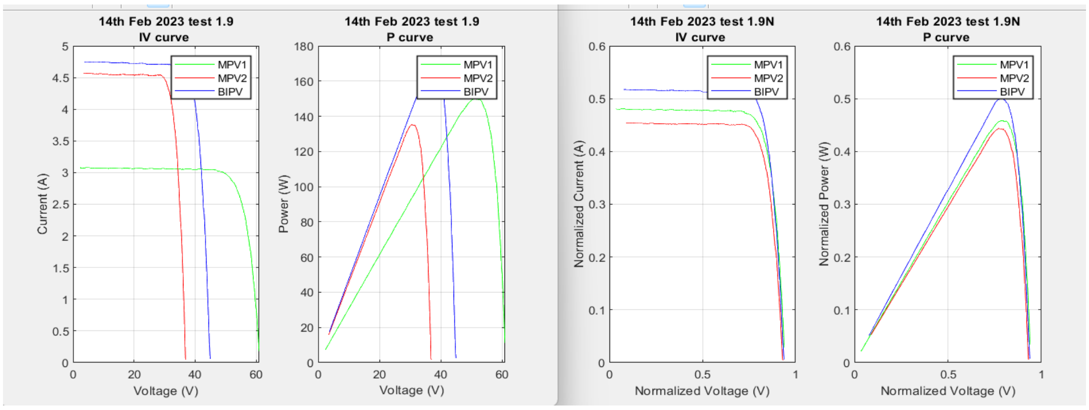

Fig. 12: I-V and P-V curves normalized and non-normalized of the test 9 day 1.

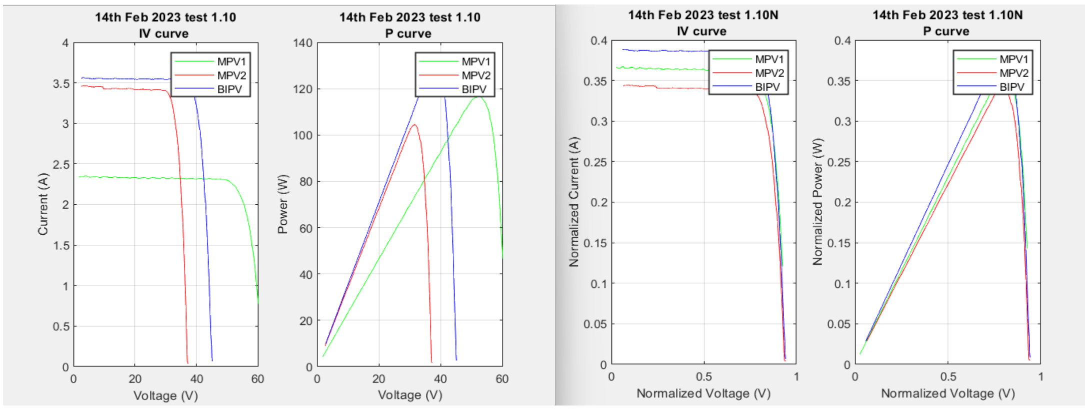

Fig. 13: I-V and P-V curves normalized and non-normalized of the test 10 day 1.

B. *Second experimental campaign graphs*

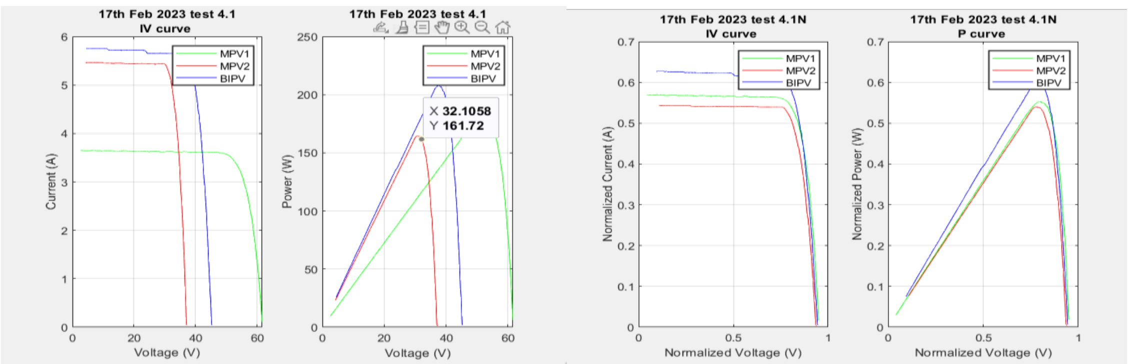

Fig. 14: I-V and P-V curves normalized and non-normalized of the test 1 day 2.

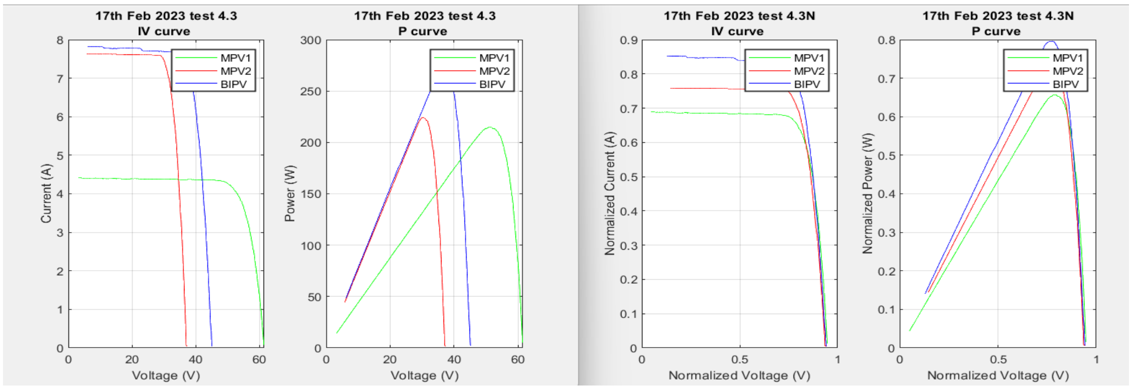

Fig. 15: I-V and P-V curves normalized and non-normalized of the test 3 day 2.

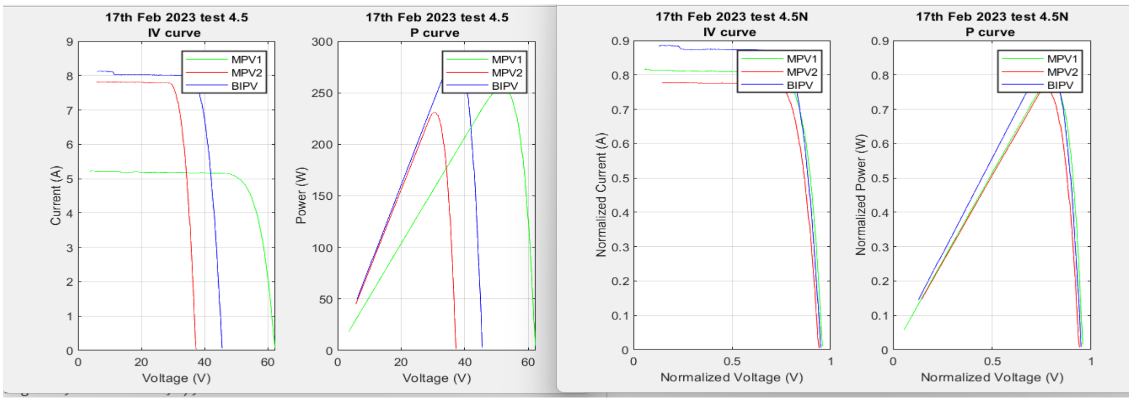

Fig. 16: I-V and P-V curves normalized and non-normalized of the test 5 day 2.

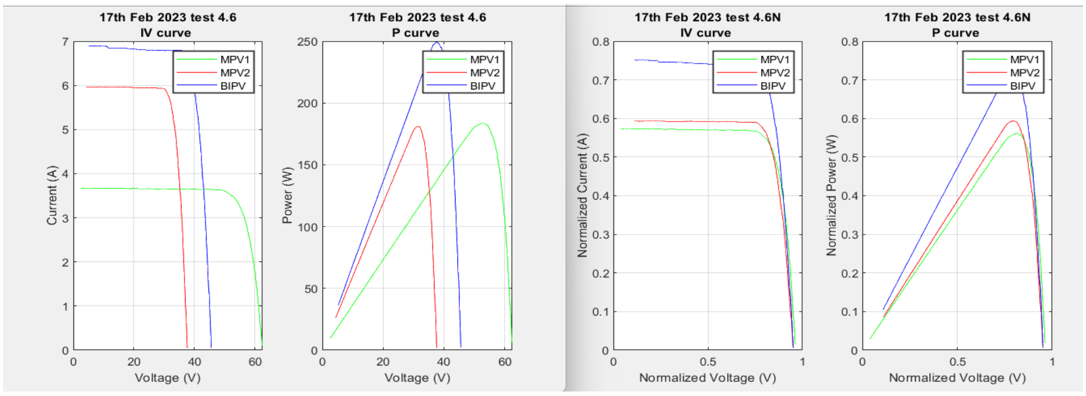

Fig. 17: I-V and P-V curves normalized and non-normalized of the test 6 day 2.

C. *Third experimental campaign graphs*

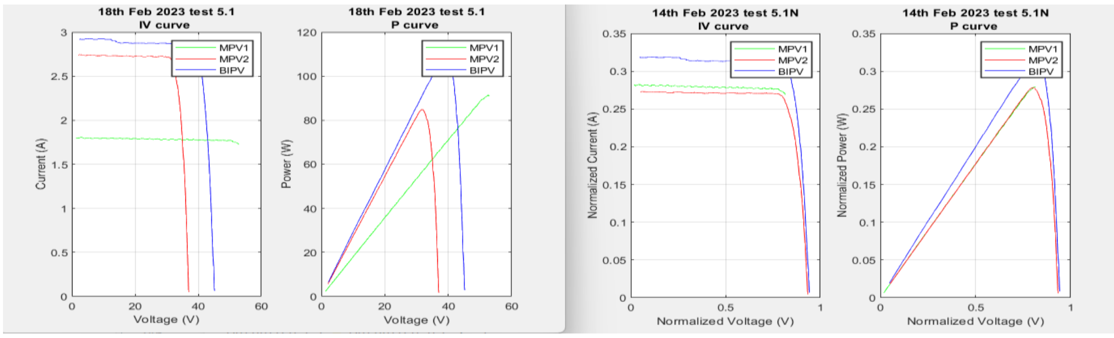

Fig. 18: I-V and P-V curves normalized and non-normalized of the test 1 day 3.

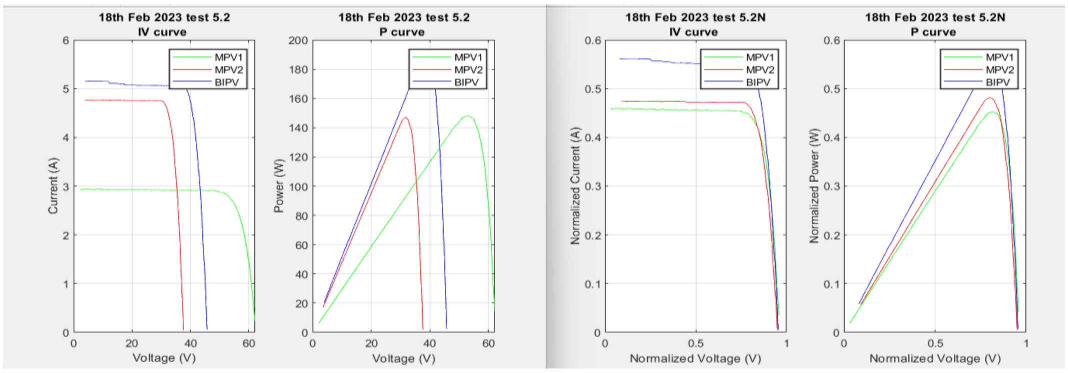

Fig. 19: I-V and P-V curves normalized and non-normalized of the test 2 day 3.

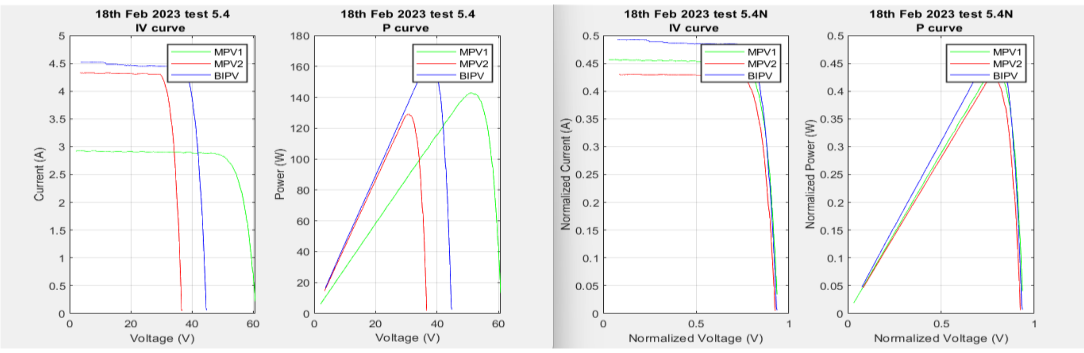

Fig. 20: I-V and P-V curves normalized and non-normalized of the test 3 day 3.

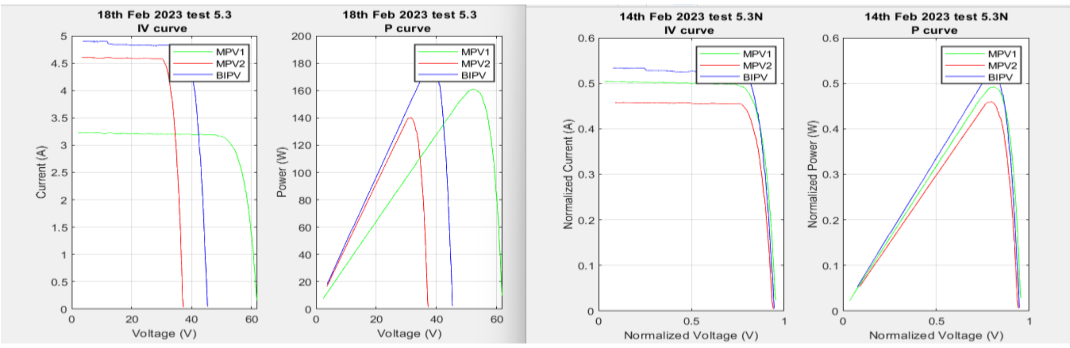

Fig. 21: I-V and P-V curves normalized and non-normalized of the test 4 day 3.

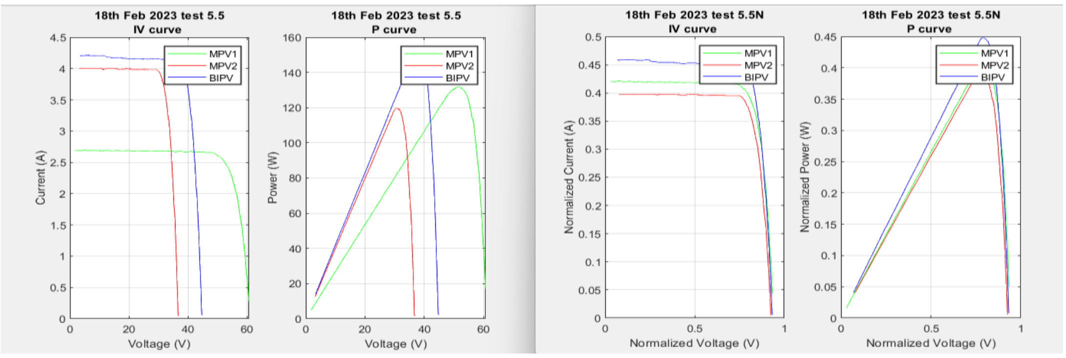

Fig. 22: I-V and P-V curves normalized and non-normalized of the test 5 day 3.

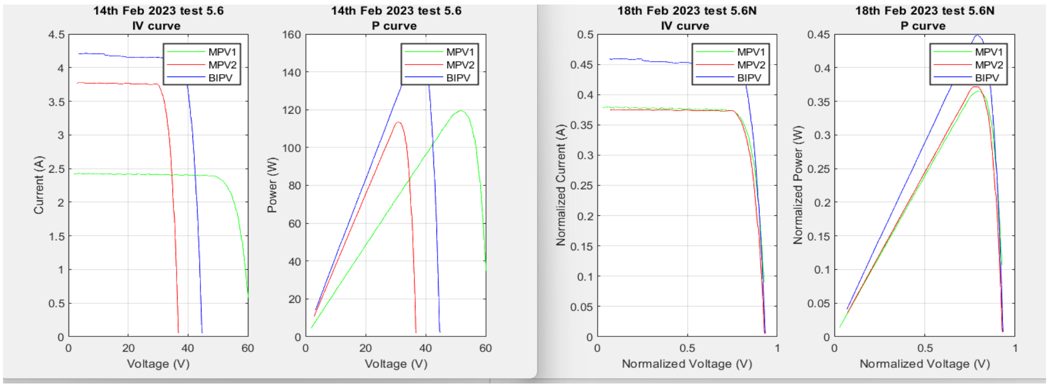

Fig. 23: I-V and P-V curves normalized and non-normalized of the test 6 day 3.

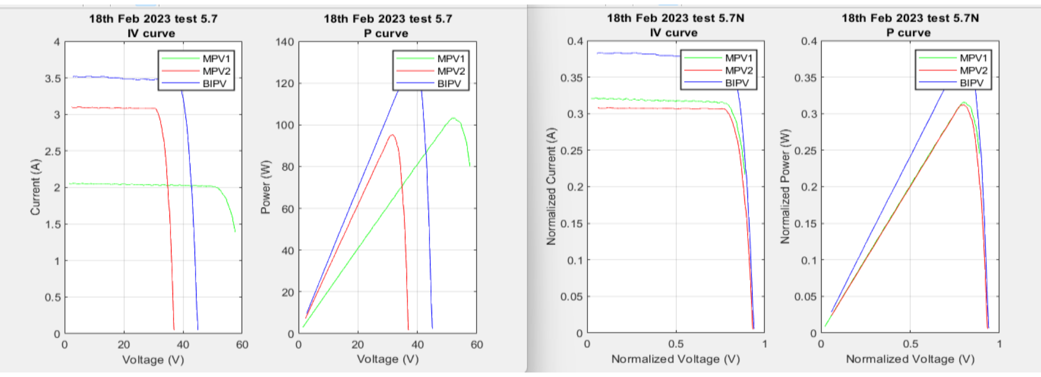

Fig. 24: I-V and P-V curves normalized and non-normalized of the test 7 day 3.

These are the graphs that were generated with the data of the tests and the Matlab code, were generated normalized and non-normalized I-V and P-V graphs. Looking to the graphs we can notice the minimum value of I_{sc} and the maximum value of U_{oc} is from the Sunpower panel. The Aleo and the Bifacial panels have a similar curve, but the Aleo panel has lower levels of I_{sc} and U_{oc} than the Bifacial panel, a media of 6.5% in terms of I_{sc} and a 22% in terms of U_{oc} in all levels of irradiance.

In terms of P_{mpp} the maximum values are from the Bifacial panel, then the Sunpower and finally in last position the Aleo panel, as in the I-V curve the minimum value of U_{oc} is from the Aleo panel, then the Bifacial curve and the maximum level is from the Sunpower panel.

Looking to the normalized graphs being the values U_{oc} constant the maximum value of the Normalized Current is of the Bifacial panel, and then the values of the other two monofacial modules are close but are in all the grpahs the Sunpower a bit higher than the Aleo panel. In terms of Normalized Power again the Bifacial has the higher value, then the values of the Aleo and Sunpower are most of the cases the same value, in some cases the Sunpower panel has a bit higher value of Normalized Power but there are more cases that the Aleo panel has higher values than the Sunpower panel.

D. Calculations to determinate important parameters

The calculated parameters are Efficiency (Ƞ), Fill Factor (FF) and Performance Index (PI).

- Efficiency (Ƞ): Refers to the ability of a solar cell, module, or photovoltaic system to convert sunlight into usable electrical energy. It's a measure of how effectively the device can harness sunlight and convert it into electricity, typically expressed as a percentage.
  This is the formula $\frac{Pmpp}{Gf*A}$.

- Fill Factor (FF): Measures the efficiency of a solar cell or module in converting sunlight into electricity. It's a key indicator of how well the solar cell can utilize the available sunlight to produce power.
  This is the formula $\frac{Impp*Vmpp}{Isc*Voc}$.

- Performance Index (PI): It is a measure used to assess the efficiency and performance of a solar power system over a specific period of time. It's a numerical value that indicates how well the system is generating electricity compared to its expected performance.
  This is the formula $\frac{FF}{FFref}$.

TABLE VII: Solar efficiency, Fill Factor and Performance Index

DAY TEST	ȠSun	ȠAleo	ȠBi	FFSun	FFAleo	FfBi	PISun	PIAleo	PIBi
1.1	14.73%	14.62%	13.71%	0.80	0.80	0.78	1.02	1.04	1.00
1.2	16.16%	15.03%	15.45%	0.79	0.78	0.77	1.01	1.02	0.99
1.3	16.40%	15.31%	15.61%	0.78	0.79	0.77	1.00	1.03	0.98
1.4	16.68%	15.55%	15.84%	0.78	0.78	0.77	1.00	1.01	0.98
1.5	16.99%	15.69%	16.14%	0.77	0.78	0.76	0.99	1.01	0.97
1.6	17.74%	15.90%	17.04%	0.79	0.78	0.78	1.01	1.01	1.00
1.7	17.74%	16.30%	17.04%	0.79	0.79	0.78	1.01	1.03	1.00
1.8	16.89%	15.69%	16.14%	0.78	0.78	0.76	1.00	1.01	0.97
1.9	18.47%	17.10%	18.09%	0.80	0.80	0.81	1.02	1.04	1.03
1.10	19.21%	17.40%	18.70%	0.83	0.81	0.82	1.06	1.06	1.05
4.1	16.04%	14.74%	15.53%	0.80	0.81	0.80	1.03	1.06	1.01
4.2	16.18%	16.37%	15.52%	0.79	0.79	0.79	1.01	1.03	1.00
4.3	18.43%	17.19%	16.77%	0.79	0.79	0.78	1.01	1.03	0.99
4.4	16.43%	15.62%	15.87%	0.81	0.82	0.83	1.04	1.06	1.05
4.5	17.94%	16.64%	17.23%	0.78	0.79	0.78	1.01	1.03	0.99
4.6	22.76%	16.80%	18.02%	0.80	0.81	0.80	1.03	1.05	1.02
5.1	18.64%	19.06%	19.64%	0.96	0.84	0.84	1.23	1.09	1.07
5.2	20.94%	18.08%	18.89%	0.81	0.82	0.82	1.04	1.07	1.04
5.3	18.92%	17.21%	19.04%	0.80	0.82	0.82	1.03	1.06	1.04
5.4	18.68%	17.13%	18.08%	0.80	0.81	0.81	1.03	1.05	1.04
5.5	18.32%	16.98%	18.17%	0.81	0.81	0.82	1.03	1.06	1.04
5.6	18.11%	17.25%	18.17%	0.82	0.81	0.82	1.05	1.06	1.04
5.7	18.15%	16.94%	19.55%	0.87	0.83	0.84	1.12	1.08	1.07
max	22.76%	19.06%	19.64%	0.96	0.84	0.84	1.23	1.09	1.07
min	14.73%	14.62%	13.71%	0.77	0.78	0.76	0.99	1.01	0.97

This graph shows the values of efficiency, fill factor and performance index of all the tests done in the three campaigns. As we can see the solar panel with the higher efficiency is the Sunpower panel with a 23% and the minimum efficiency is from the Bifacial panel with a 14%. The maximum value of the FF is 0.96 probably this value don't reflect the reality because is far from the other average values of FF, this is because this test was realized with a irradiance less than 300 G/m^2, the next max value is 0.87 which is near to the average value, this max value is for the Sunpower panel, the minimum value is 0.76 for the Bifacial panel. The maximum value of PI is 1.23 as we comment before is a value that is far from the average the next value is 1.12 for the Sunpower panel and the minimum value is 0.97 for the Bifacial panel.

TABLE VIII: Solar efficiency, Fill Factor and Performance Index in order of irradiance

DAY TEST	G total G/m^2	Tcell ºC	ȠSun	ȠAleo	ȠBi	FFSun	FFAleo	FfBi	PISun	PIAleo	PIBi
1.1	366.27	32.06	19.21%	17.40%	18.70%	0.83	0.81	0.82	1.06	1.06	1.05
5.5	432.51	35.51	18.11%	17.25%	18.17%	0.82	0.81	0.82	1.05	1.06	1.04
5.3	500.34	31.22	18.68%	17.13%	18.08%	0.80	0.81	0.81	1.03	1.05	1.04
1.7	689.89	38.15	17.74%	16.30%	17.04%	0.79	0.79	0.78	1.01	1.03	1.00
1.2	850.34	38.02	16.16%	15.03%	15.45%	0.79	0.78	0.77	1.01	1.02	0.99
1.4	892.55	36.99	16.68%	15.55%	15.84%	0.78	0.78	0.77	1.00	1.01	0.98

This are the values collected in the Table VII, but now in order of irradiance from 366.27 G/m^2 to 892.55 G/m^2 , this tests are selected because are the ones that we have almost the same irradiance in the three solar panels, so we can compare them more exactly. In most of the tests the Sunpower one has the highest value of Efficiency, Fill Factor but in the Performance Index the Aleo panel has the maximum values, which is an important index to consider because is the value of the Fill Factor against the value of the Fill Factor of the nominal numbers of the solar module. However the minimum values are from the Aleo panel in terms of Efficiency and Fill Factor. As the irradiance get higher the factors get lower values this is because the temperature cell get higher and is more difficult to transform the irradiance into power, but as more irradiance get into the solar panel more power is generated.

IV. CONCLUSION

This experimental research work related to the comparison of the Bifacial module and two traditional monofacial modules (Sunpower and Aleo) realized with different solar irradiance and different cell temperature. The I-V and P-V are strongly related to irradiance. The data used to analyze the three modules was got by testing the solar panels in different days, concrete form the 14th of February to 18th of February 2023 in the SolarTech^{LAB} , Department of Energy of the Politecnico di Milano, Italy. In terms of power generation the Bifacial module produces a 12% more power the the Sunpower module and a 24% than the Aleo module. Also the normalized curves show that with a constant value of tension, the Bifacial module has the maximum value of I_{sc} and the minimum value is from the Aleo module. Considering the Eficiency, Fill Factor the Sunpower module has the best results, but in terms of Performance Index the Aleo module has the highest numbers compared with the other two modules. To conclude if the achievement is to produce the maximum power possible without taking to account of efficiency the best option is the Bifacial module, but the best performance is done by the Sunpower module, getting the higher values of Efficiency.

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