POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

Investigation of the shading effect on the performance of a grid-connected PV plant in Samsun/Turkey

Samsun ilinde şebekeye bağlı bir FV tesisinin performansına gölgelenme etkisinin incelenmesi

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Keskin V., Pour Rahmati Khalejan S. H. and Çıkla R., "Investigation of the shading effect on the performance of a grid-connected PV plant in Samsun/Turkey", ***Politeknik Dergisi***, 24(2): 553-563, (2021).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.701525

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Highlights

- *The effect of shading, caused by a mis-located transformer building on the performance of a PV array*
- *The largest shaded area is observed as 18.05 m^2 on the panels on September 30, 2018 at 06:45.*
- *The energy loss due to shading is 307 kWh (0.66%) of a 30 kW-PV array for 12 month.*

Graphical Abstract

In this study, shading caused by a mislocated transformer building on the performance of an on-grid solar power plant were investigated under the outdoor climatic conditions on clear and sunny days for 12 months.

Figure. Shaded area formed on the panels

Aim

The aim of this work is to investigate the shading effect on a grid-connected solar power plant in Samsun which started in June-2018 until May-2019 for 12 months.

Design & Methodology

The measurements of the shaded area for each month were started with the sunrise in cloudless and clear weather, continued until the shade vanishes on the panels.

Originality

Shading caused by a mislocated transformer building of a PV array in an on-grid solar power plant.

Findings

It is obvious that the power loss due to the shading effect will reach up to MW scale when considered that the photovoltaic energy systems have lifetime of 25-30 years

Conclusion

The long-term shading significantly affects the performance and other sensitive components in a PV power plant.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Samsun/Türkiye'de Şebekeye Bağlı bir FV Tesisin Performansına Gölgelenme Etkisinin İncelenmesi

Araştırma Makalesi / Research Article

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(Geliş/Received : 10.03.2020 ; Kabul/Accepted : 04.05.2020)

ÖZ

Fotovoltaik (FV) sistemlerde, güç üretimi güneş panellerinin kısmi veya tamamen gölgelenmesinden önemli ölçüde etkilenir.Bu çalışmada, bir transformatör binasının neden olduğu gölgelemenin şebekeye bağlı bir güneş enerjisi santralindeki FV dizisinin performansı üzerindeki etkileri gerçek çalışma koşulları altında araştırılmıştır. Gölgeli ve gölgesiz dizinin performansları, 12 ay boyunca açık ve güneşli günlerde dış iklim koşullarında düzenli olarak gözlemlenmiştir. Performans verilerinin değerlendirilmesi sonucunda, santralin bir yıllık çalışmasının ardından, trafo binasına bağlı toplam güç kaybının gölgeli 30 kW FV dizisinde 307 kW (% 0,66) olduğu hesaplanmıştır. Fotovoltaik enerji sistemlerinin 30 yıla kadar kullanım ömrü olduğu düşünüldüğünde, gölgeleme etkisinin neden olduğu güç kaybının MW ölçeğinde güce ulaşacağı açıktır. Bu gözlem, bir FV enerji santrali tasarlarken operasyonel birimlerin önemini vurgulamaktadır.

Anahtar Kelimeler: Kısmi gölgeleme, sürdürülebilirlik, fotovoltaik, FV dizisi, güç kaybı.

Investigation of the Shading Effect on the Performance of a grid-connected PV Plant in Samsun/Turkey

ABSTRACT

In photovoltaic (PV) systems, power generation is significantly affected by partial or complete shading of solar panels. In this study, the effects of shading caused by a transformer building on the performance of a PV array in an on-grid solar power plant were investigated under real operating conditions. The performaces onf the shaded and the unshaded array were regularly observed under the outdoor climatic conditions on clear and sunny days for 12 months. As a result of the evaluation of performance data, the total power loss due to the transformer building was calculated to be 307 kW (0.66%) in the shaded 30 kW-PV array after one-year operation of the power plant. It is obvious that the energy loss caused by the shading effect will reach up to power in MW scale when considered since photovoltaic energy systems have lifetime up to 30 years. This observation underlines the importance of the operational units when designing a PV power plant.

Keywords: Partial shading, sustainability, photovoltaics, PV array, power loss.

1. INTRODUCTION

The performance of photovoltaic (PV) systems are negatively affected by a number of parameters such as irradiation, operating temperature, reflection, pollution, shading and so on [1, 2]. Among these parameters, temperature and shading effect are the main factors [3-5]. Complete or partial shading of incoming sun rays is caused by the clouds, adjacent buildings, towers, trees, telephone and electricity poles. It is known that shading caused by these factors reduces the power generation and the efficiency of a PV power plants. It is possible to install power plants from kW to GW scale from solar panels [6, 7]. At the same time, the shaded panels in modules absorb the electrical power produced by other cells of a PV panel, causing the formation of hot spots and can cause irreversible damage [8-10]. Some technological devices and semiconductor circuit elements such as bypass diodes, MOSFET, direct current-direct current (DC-DC) optimizers, micro inverters and Maximum power point tracking (MPPT) algorithms are used to reduce the energy losses [11, 12]. It cannot be said that these applications completely eliminate the power losses caused by shading [13-15]. There are various studies regarding complete or partial shading effect on PV module or power plant. In this contex, Fatih Bayrak et al. studied on the partial shading effect on power output, energy and exergy efficiency of the solar panel [16], also they invastigated Effects of different parameters on temperature and efficiency for cooling of photovoltaic panels under natural convection [17]. Dolara et al. studied the shading effect on two different mono-crystalline and poly-crystalline PV modules [3]. Şener Parlak proposed a new reconfiguration method for photovoltaic arrays under partial shading conditions [18] and new MPPT method for PV array system operating partially shaded conditions [19]. Chan highlighted the importance of considering the

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adjacent building shading effect on a PV system integrated building glass application in Hong Kong city for system performance and energy payback time (EPBT) [20]. Alonso et al investigated shading effects in photovoltaic arrays, in their studies the influence of the amount of shading, the type of reverse characteristic of the cell, the string length and the number of shaded cells has been analysed [21]. Ersoy Beşer studied the PV simulator structure for modelling PV arrays, in his study, a new PV simulator structure is proposed for modeling PV panels in laboratory environment under partical shading [22]. Sangram Bana et al. investigated the effect of uniform and non-uniform shading scenarios on the output of solar photovoltaic modules of different interconnection schemes [23]. Başay et al. analyzed the selection of photovoltaic panels consisting of shading, monthly and yearly average and solar radiation in Orhaneli County of the province of Bursa [24]. Schill et al. experimentally studied the effect of (partial shading) on current-voltage curve of PV panels. They showed that the efficiency of PV panels has decreased 20% from the first measurement in 5 months [25]. Vijayalekshmy et al. proposed a novel Zig-Zag scheme of array for the total cross tied interconnection of PV modules for decreasing partial shading losses. Their main aim was to increase power generation of PV systems. Their results show that the new scheme of rearrangement lessens the number of multiple local maxima in power-voltage characteristics which further simplifies the MPPT algorithm[26]. Adak et al. analayzed Simulink equivalent of the PV system for partial shading on PV panels. In their studies I-V and P-V curves were found for partial shaded conditions [27]. The aim of this work is to investigate the shading effect on a grid-connected solar power plant in Samsun which started in June-2018 until May-2019 for 12 months. (Fig.1). In the plant, the transformer building was surprisingly mis-located which was shading a group of panels. This enabled us to investigate the shading effect under real conditions. The measurements of the shaded area for each month were started with the sunrise in cloudless and clear weather, continued until the shade vanishes on the panels. The voltage (V), current (I), instant power generation and total power generation values were read on both inverters. The data obtained were analyzed by comparing the power performance data obtained from shading Inverter (Sh-Inv) of the PV array with those of unshaded Inverter (USh-Inv).

2. DESCRIPTION OF THE ON-GRID PV POWER PLANT AND METHOD

2.1 PV Power Plant

The PV plant has a capacity of 480 kW and is built on an area of 10000 m2. The layout of the power plant is shown in Figure 1. The support structures with fixed tilt angle were preferred for mounting of the photovoltaic modules.

In order to make maximum use of the sunlight in summer and winter, the modules were mounted on the steel stands facing South and with an inclination angle of 23^o. Since the area where the power plant was mounted has natural slope of 8^o degrees the panel array stands are positioned on the land at an angle of 15^o to capture the 23^o angle.

Figure 1. Satellite image of the pv power plant. Transformer building (red arrow), shaded string (yellow arrow) unshaded string (blue arrow).

The solar radiation and climate modeling data obtained from the simulation program (suncalc) are illustrated in Figure 2. [28]. The geographical coordinates of the PV plant are 41.27635^o N latitude, 36.17665^o E and altitude of 292 m. The PV plant under investigation was mounted with the support of the European Union project.

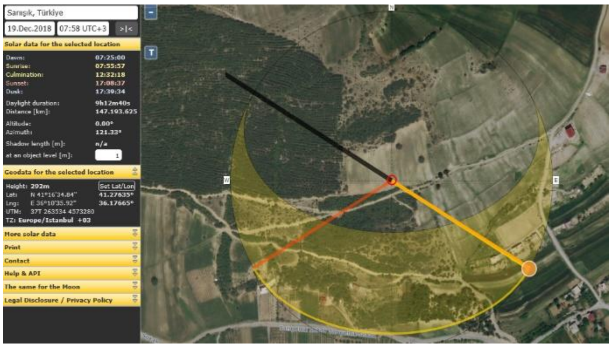


Figure 2. Solar data on December 18, 2018 at 07.58 am for PV plant location

During the installation phase, current-power measurement characteristics were made according to IEC 60904-1 [29]. Current-voltage values were measured according to solar irradiation and temperature characteristics IEC 60891 [30]. Plant commissioning and grid connection controls were performed according to IEC 62446-1 standards [31]. The PV power plant consists of 1920 poly-crystalline panels each with maximum output of 260 W [32], and the electric current generated from the sun is controlled by 16 inverters of 30 kW [33] and one 630 kVA transformer [34]. Each of the inverters has double (MPPT) that enables to achieve and maintain maximum power by matching the I-V operating point [35]. Two arrays of the same number of PV panels (each with 120 panels) were selected for the observations. One of the arrays is connected to the Sh-Inv subject to the shading while USh-Inv is not affected by shading.

2.2. Method

This study started in June-2018 and continued until May-2019 for 12 months. The effects of shading, sunlight hour (t_{sun}) and power output ratio (R_P) on the PV plant efficiency were analyzed referring to the voltage (V), current (I) and power (P) data obtained from the inverters. As the altitude of the sun, azimuth and zenith angles change depending on the months and daily time zone, the area of the shadow changes as well. The shaded area of the transformer building was calculated with the intervals of 15 minutes and the effect of the shading on performance was observed regularly by the following steps:

- The measurements of the shaded area for each month were started with the sunrise in cloudless and clear weather, continued until the shade vanishes on the panels.
- During shading, photographs were taken and the shaded area was measured. Thus, the number of panels affected by shading and the ratio of the shaded area to the total area of the array were calculated.
- The voltage (V), current (I), instant power generation and total power generation values were read on both inverters.
- The data obtained are analyzed (see section 3.2).

2.2.1. Calculations and data processing

As known, the shading adversely affects the performance of PV panels. Therefore, while positioning the PV plant components (panels, inverters, transformer building, etc.), the distance between them must be calculated correctly. Otherwise, as in PV plant under study, the shadow of the transformer building negatively affects the performance of a group of panels connected to Sh-Inv. The minimum distance L between the shading objects and the PV panels (Figure 3) can be calculated using the Equation 1 [36].

$$\mathrm{L} > \frac{\mathrm{H}}{\tan\alpha} \quad (1)$$

where (H) is the height from the lower point of the panel to the top of the transformer building and (α) is the angle incidence of the sunlight rays.

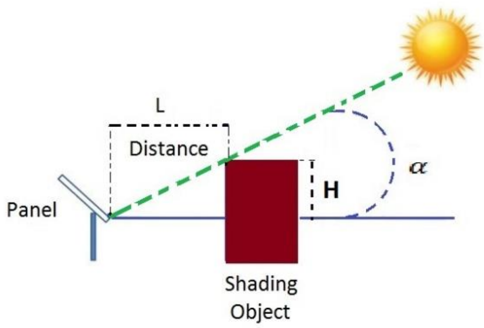


Figure 3. Distance L from panel to shading object.

Shaded area (A_S), total array area (A_T), power losses (P_L) and total power (P_T) are used to find the ratio of shaded area (R_A) and ratio of power loss (R_P) in the Equation 2 and 3;

$$R_A = \frac{A_S}{A_T} \quad (2)$$

$$R_P = \frac{P_L}{P_T} \quad (3)$$

As shown in Figures 4 (a-f), the shaded area formed on the panels changes depending on months and daytime. Approximate values were obtained by using simple geometric calculations to find the shaded area in m^2. Shaded area (A_S), total array area (A_T) and ratios found at the end of the calculations are shown for each month respectively in Tables 1and Tables (A-k) in Appendix. In this study, USh-Inv and Sh-Inv values and shaded area ratios are illustrated in tables and plots in Section 3. The average daily sunlight time (hours) was calculated over the total production amount of the arrays with respect to 1000 W/m^2 solar irradiation. The solar irradiation times were calculated by using the obtained power generation data and given in Table 2. Then, the irradiation time data under standard conditions (STC) for Samsun province which was taken from Turkish Meteorological Service (MGM) were compared with the energy production in shaded and unshaded arrays. The following calculations (4, 5) were made with the energy generation data for one year in which P_E represents the expected monthly production amount and P is the power read from the inverter, T_S is the irradition time (hour) and D is the number of clear and sunny days and so the observed irradiation times were calculated. The data obtained are illustrated in Table 2 and Fig.6 (see Section 3.3).

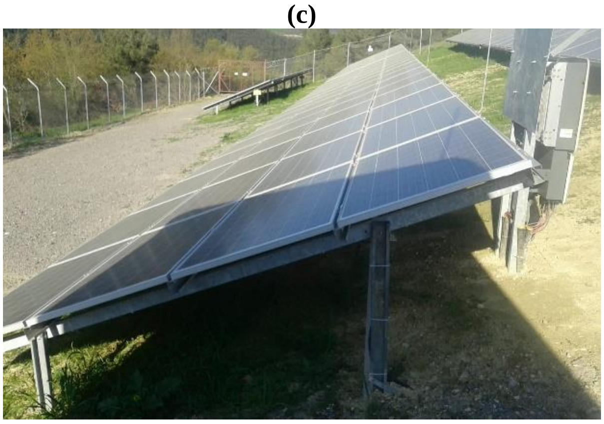
$$P_E = PT_SD \quad (4)$$

$$T_S = \frac{P_E}{PD} \quad (5)$$

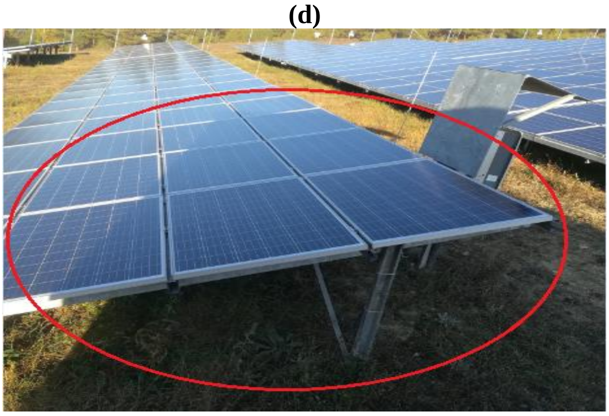
(a)

(b)

(c)



(d)



(e)

(f)

Figures 4 (a-f). The shaded area formed on the panels changes depending on months and daytime. (A) Image of taken on June 30 at 05:40, (B) Image of taken on June 30 at 06:25, (C) Image of taken on July 26 at 07:05, (D) Image of taken on July 26 at 08:05,(E) Image of taken on September 30 at 07:20 and (F) Image of taken on September 30 at 07:40

3. RESULTS AND DISCUSSION

3.1. Power loss and ratio per month

This study started in June 2018 and continued until May 2019. Observations were made during the last week of each month, when the weather was cloudless and sunny. The data for the instant power were obtained from the arrays connected to Sh-Inv and USh-Inv (Table 1) and tables A-K in Appendix. Power (P) and Loss ratio (R_L) vs. Time (t) curves are shown in Figure 5 and Figures (A-K) in Appendix. The difference in power generation between two arrays measured from USh-Inv and Sh-Inv is illustrated in Figures 5 and Figures (A-K) in Appendix.

3.2. Shading area and ratio per month

The dimensions of each poly-crystalline panels are 1680x1000x40 mm (1.68 m^2). The shaded area values along with produced energy values are comparatively given in Table1 and (A-K) in Appendix and in Figure 5 and (A-K) in Appendix.

As seen in Table 1and Figure 5, the power loss ratio changes between 1.81% and 4.85%. The lowest power loss was observed as 16 Wp at 5:40. The highest power loss was recorded as 330 Wp at 07:55. The largest shaded area on the panels was observed as 12.1 m^2 at 07:10. The shaded ratio between 0.70% and 6%.

Table 1. Instant production, power loss ratios and shaded area data for June 30, 2018.

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L) Lost Power (Wp)	(%)	Shaded Area (A_S) m²	(%)
05:40	718	702	16	2.22	1.84	0.91
05:55	876	858	18	2.05	2.13	1.05
06:10	1127	1104	23	2.04	2.84	1.41
06:25	1452	1418	34	2.34	5.37	2.66
06:40	2896	2810	86	2.97	7.38	3.66
06:55	3749	3631	118	3.15	9.85	4.88
07:10	4973	4833	140	2.81	12.11	6.00
07:25	6428	6116	312	4.85	10.35	5.13
07:40	8522	8235	287	3.36	7.50	3,72
07:55	10020	9690	330	3.29	6.26	3.10
08:10	11700	11410	290	2.48	4.55	2.25
08:25	14100	13860	170	1.70	3.06	1.52
08:40	15210	15030	180	1.18	1.42	0.70

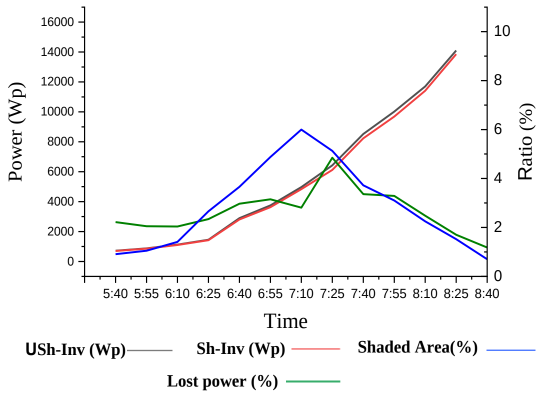


Figure 5. Instant production data and ratios for June 30,2018

3.3. Annually solar irradiation time

Taking into account the reference solar irradiation of 1000 W / m^2, the average daily solar irradiation time (hour) was calculated over the total production amount of the array. The calculated values and those provided by Turkish Meteorological Service were compared in Table 2 and Figure 6.

3.4. Discussion

According to the obtained values, the power loss ratios were between 1.15% and 13.50%. The lowest power loss was observed as 16 W in June 30, 2018 at 05.40 (Table 1). The highest power loss was recorded 878 W in March 28, 2019 at 07.55 (Table I in Appendix). When unshaded array power generation is referenced, the amounts of power losses (from 16 W to 878 W) give ratios of 2.2% and 9.37%, respectively. When the power loss amount is calculated on monthly basis, the lowest loss were observed in August 2018 with 11 kW and the highest loss in November 2018 with 51 kW (see Table 2).

The largest shaded areas on the panels are observes 18.05 m^2 on September 30, 2018 at 06.45, 17.45 m^2 on March 28, 2019 at 06.25 and 17.02 m^2 on August 27, 2018 at 07.20. It was noted that the shading area is wider on the panels in September, October and March, causing the ratio curve to decrease linearly. Although the curves for November, December, January and February are similar to those of September, October and March where the shaded area on the panels were smaller. On the other hand, June, July, August, April and May have parabolic curves. The ratio of the shaded area to the total array area were calculated to be 0.22% and 8.95% for the maximum and minimum shading.

Table 2. Comparison of solar irradiation times

Months	Monthly Production Quantities USh-Inv (kW)	Sh-Inv (kW)	Poduction Difference Monthly Difference (kW)	Obtianed Production Time (Hour) Unshaded	Shaded	Solar Irradiation time taken from MNG for Samsun province (average between 1929-2018) (Hour)
June.18	5819	5806	13	6.46	6.45	8.3
July.18	6231	6212	19	6.70	6.68	8.8
Agu.18	5396	5385	11	5.80	5.78	8.2
Sep.18	4681	4668	13	5.20	5.18	6.3
Oct.18	3803	3786	17	4.10	4.07	4.6
Nov.18	3281	3230	51	3.64	3.59	3.7
Dec.18	2596	2564	32	2.79	2.75	2.7
Jan.19	1896	1858	38	2.03	1.99	2.7
Feb.19	2221	2186	35	2.64	2.60	3.2
Mar-19	2702	2680	22	2.90	2.88	3.6
Apr.19	3446	3427	19	3.82	3.80	4.7
May-19	4579	4567	12	4.92	490	6.2
Annually Totals:	46651	46369	307	51.00	50.67	63.00
Daily Average Solar Irradiation Time (Hour):				4.25	4.22	5.25

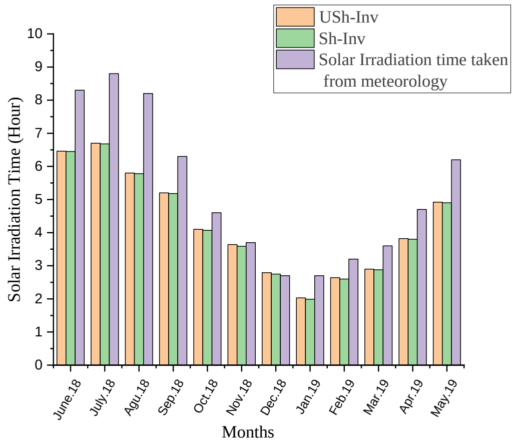


Figure 6. Comparison of solar irradiation times

4. CONCLUSION

The loss ratio in power generation was observed to be affected significantly by the size of the shaded area and the incidence angle of the sunlight irradiation. The annual amount of power loss caused by mis-located transformer building was observed as 307 kW (0.66%) in a 30 kW-array after a period of 2-3 hours in the early hours of the morning. It is obvious that the power loss due to the shading effect will reach up to MW scale when considered that the photovoltaic energy systems have lifetime of 25-30 years. In addition, the calculated solar irradiation times were shown to be different from the values provided by MGM. Based on the results and observations, it can be concluded that the long-term shading significantly affects the performance and other sensitive components in a PV power plant.

ACKNOWLEDGEMENT

We would like to thank the PV plant owners for giving us this opportunity to work.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Vedat KESKİN: Supervision, Conceptualization, Methodology, Visualization, Investigation, Writing- Reviewing and Editing the manuscript.

Seyed Hamed Pour Rahmati KHALEJAN: Data curation, Software, Validation, Writing- Original draft preparation.

Recep ÇIKLA: Writing- Original draft preparation, Software, Performed the experiments and analysed the results.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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Appendix

Section 1. Tables

Table A. Instant production, power loss ratios and shaded area data for July 26, 2018.

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L)		Shaded Area (A_S)	
			Lost Power (Wp)	(%)	m^2	(%)
05:50	732	707	25	3.40	3.25	1.61
06:05	1147	1086	61	5.30	4.16	2.06
06:20	1507	1399	108	7.16	5.86	2.90
06:35	2347	2142	205	8.73	8.97	4.44
06:50	4051	3638	413	10.2	13.03	6.46
07:05	5163	4664	499	9.66	14.75	7.31
07:20	7243	6647	596	8.22	12.20	6.05
07:35	8564	7985	579	6.76	9.92	4.92
07:50	10390	9952	438	4.21	5.59	2.77
08:05	12870	12410	460	3.57	4.23	2.10
08:20	14320	13890	430	3.00	3.83	1.90
08:35	15640	15250	390	2.49	0.85	0.42

Table B. Instant production, power loss ratios and shaded area data for August 27, 2018.

Observon times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L)		Shaded Area (A_S)	
			Lost Power (Wp)	(%)	m^2	(%)
06:05	864	808	56	6.48	7.42	3.68
06:20	1174	1096	78	6.64	8.9	4.41
06:35	1629	1526	103	6.32	10.05	4.98
06:50	3486	3202	284	8.14	12.15	6.02
07:05	5327	4818	509	9.55	13.87	6.88
07:20	7182	6357	825	11.48	17.02	8.44
07:35	9392	8680	712	7.58	12.90	6.40
07:50	11520	10880	640	5.55	9.50	4.71
08:05	13570	13100	470	3.46	5.85	2.90
08:20	16070	15780	290	1.80	2.04	1.01

Table C. Instant production, power loss ratios and shaded area data for September 30, 2018.

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp))	Difference between Unshaded and Shaded (P_L)		Shaded Area (A_S)	
			Lost Power (Wp)	(%)	m^2	(%)
06:45	654	581	73	11.16	18.05	8.95
07:00	1315	1178	137	10.42	16.43	8.15
07:15	3501	3269	232	6.62	14.70	7.29
07:30	5295	4807	488	9.21	11.07	5.49
07:45	7196	6379	817	11.53	8.65	4.29
08:00	9211	8412	799	8.67	6.15	3.05
08:15	12360	11790	570	4.61	4.20	2.08
08:35	14730	14380	350	2.37	2.23	1.10

Table D. Instant production, power loss ratios and shaded area data for October 28, 2018

Observation times (t)	USh- Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L)		Shaded Area (A_S)	
			Lost Power (Wp)	(%)	m^2	(%)
07:15	421	384	37	8.79	12.75	6.32
07:30	743	680	63	8.48	10.20	5.06
07:45	1135	1009	126	11.10	8.55	4.24
08:00	2079	1895	184	8.85	7.14	3.54
08:15	4193	3904	289	6.89	6.00	2.97
08:30	7562	7065	497	6.57	4.74	2.35
08:45	10530	9988	542	5.14	2.18	1.08
09:00	13890	13420	470	3.38	1.03	0.51

Table E. Instant production, power loss ratios and shaded area data for November 29, 2018.

Observation times (t)	USh-inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L)		Shaded Area (A_S)	
			Lost power (Wp)	(%)	m^2	(%)
07:35	402	373	29	7.21	6.43	3.19
07:50	701	659	42	5.99	5.6	2.77
08:05	1.024	961	63	6.15	4.35	2.15
08:20	2413	2311	102	4.22	3.47	1.72
08:35	3982	3833	149	3.74	2.50	1.24
08:50	6015	5802	213	3.54	1.62	0.80
09:05	8138	7852	286	3.51	0.95	0.47
09:20	10790	10540	250	2.31	0.40	0.20

Table F. Instant production, power loss ratios and shaded area data for December 30, 2018.

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L)		Shaded Area (A_S)	
			Lost Power (Wp)	(%)	m^2	(%)
08:00	322	303	19	5.9	4.82	2.39
08:15	414	396	18	4.35	4.06	2.01
08:30	854	825	29	3.39	3.55	1.76
08:45	1172	1133	39	3.33	2.40	1.19
09:00	1837	1715	118	6.42	1.85	0.91
09:15	3784	3619	165	4.36	1.15	0.57
09:30	7852	7384	468	5.96	0.70	0.35

Table G. Instant production, power loss ratios and shaded area data for January 30, 2019.

Observation times (t)	USh-Inve (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L) Lost Power (Wp)	(%)	Shaded Area (A_S) m^2	(%)
07:50	367	340	27	7.35	6.20	3.07
08:05	485	453	32	6.59	5.52	2.74
08:20	921	874	47	5.10	4.1	2.03
08:35	1214	1.142	72	5.93	3.25	1.61
08:50	2150	2.024	126	5.86	2.42	1.20
09:05	4516	4.281	235	5.2	1.55	0.77
09:20	9054	8.567	487	5.37	0.82	0.41

Table H. Instant production, power loss ratios and shaded area data for February 27, 2019.

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L) Lost Power (Wp)	(%)	Shaded Area (A_S) m^2	(%)
07:15	430	382	48	11.16	8.45	4.19
07:30	694	619	75	10.8	7.06	3.50
07:45	1104	1013	91	8.24	5.79	2.87
08:00	1920	1772	148	7.71	4.35	2.16
08:15	3097	2828	269	8.68	3.22	1.60
08:30	5824	5326	498	8.55	2.55	1.26
08:45	7823	7431	392	5.01	1.93	0.95
09:00	10040	9787	253	2.52	1.05	0.52
09:15	12620	12440	180	1.42	0.45	0.22

Table I. Instant production, power loss ratios and shaded area data for March 28, 2019

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L) Lost power (Wp)	(%)	Shaded Area (A_S) m^2	(%)
06:25	886	832	54	6.09	17.45	8.65
06:40	1184	1093	91	7.68	15.08	7.48
06:55	2295	2065	230	10.02	13.25	6.57
07:10	3762	3254	508	13.50	12.65	6.27
07:25	5190	4525	665	12.81	9.40	4.66
07:40	6927	6132	795	11.47	7.90	3.92
07:55	9371	8493	878	9.37	6.03	3.00
08:10	11090	10380	710	6.40	4.32	2.14
08:25	12260	11870	390	3.20	2.70	1.34

Table J. Instant production, power loss ratios and shaded area data for April 30, 2019.

Observation times (t)	USh-Inv (Wp)	Sh-Inve (Wp)	Difference between Unshaded and Shaded (P_L) Lost Power (Wp)	(%)	Shaded Area (A_S) m^2	(%)
05:35	883	841	42	4.75	7.25	3.59
05:50	1168	1090	78	6.68	9.8	4.86
06:05	2592	2403	189	7.30	11.50	5.70
06:20	3351	3066	285	8.50	13.65	6.77
06:35	4835	4443	392	8.10	10.90	5.4
06:50	6489	6.019	470	7.24	8.30	4.11
07:05	7982	7503	479	6.00	7.55	3.74
07:20	10040	9553	487	4.85	6.20	3.07
07:35	11800	11390	410	3.47	4.98	2.47
07:50	13150	12800	350	2.66	3.15	1.56
08:05	14420	14220	200	1.38	1.62	0.80

Table K. Instant production, power loss ratios and shaded area data for May 29, 2019.

Observation times (t)	USh-Inv (Wp)	Sh-Inv (Wp)	Difference between Unshaded and Shaded (P_L) Lost Power (Wp)	(%)	Shaded Area (A_S) m^2	(%)
05:30	1238	1188	50	4.04	6.20	3.07
05:45	2204	2097	107	4.85	8.57	4.25
06:00	3793	3531	262	6.90	10.25	5.08
06:15	5015	4692	323	6.44	12.04	5.97
06:30	7261	6842	419	5.77	13.50	6.69
06:45	9084	8621	463	5.10	11.07	5.49
07:00	10920	10450	470	4.30	7.83	3.88
07:15	12030	11640	390	3.24	5.03	2.49
07:30	13590	13250	340	2.50	2.78	1.38
07:45	14870	14690	180	1.21	1.53	0.76

Section2.Figures

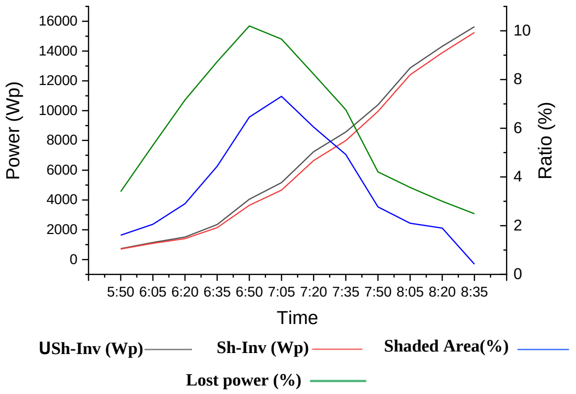

Figure A. Instant production data and ratios for July 26, 2018.

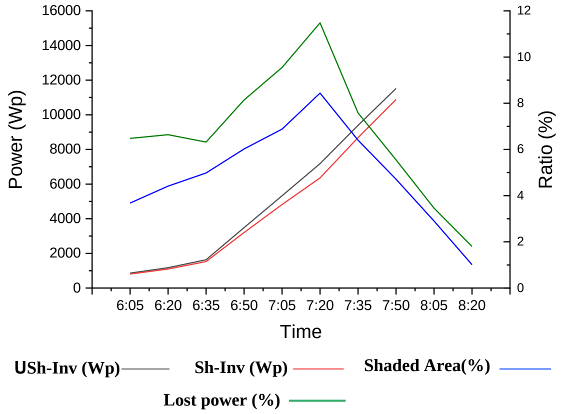

Figure B. Instant production data and ratios for August 27, 2018.

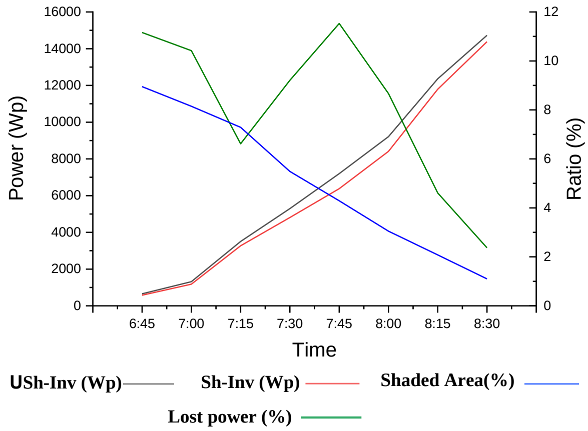

Figure C. Instant production data and ratios for September 30, 2018.

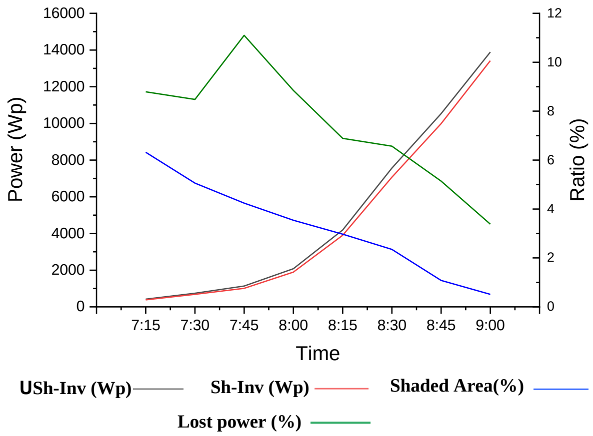

Figure D. Instant production data and ratios for October 28, 2018

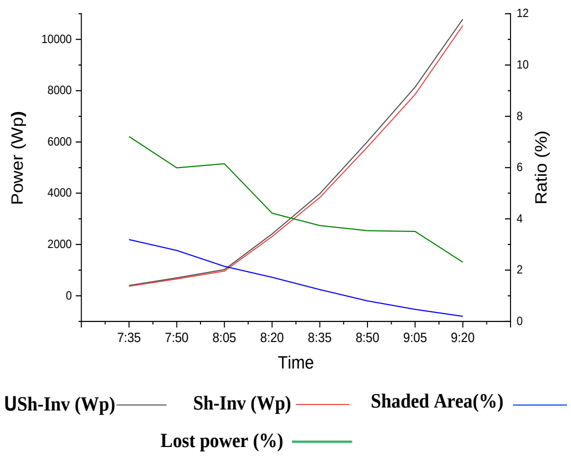

Figure E. Instant production data and ratios for November 29, 2018.

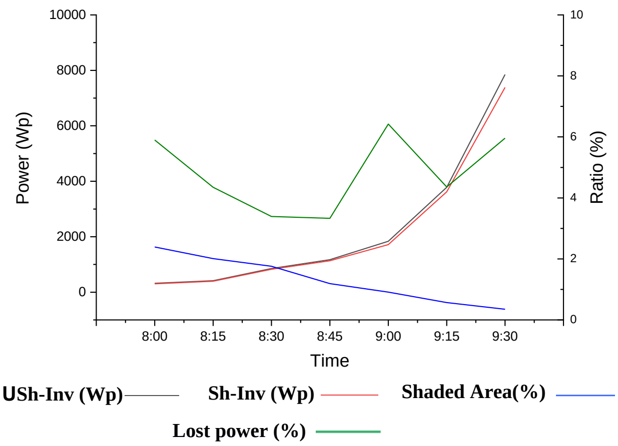

Figure F. Instant production data and ratios for December 30, 2018.

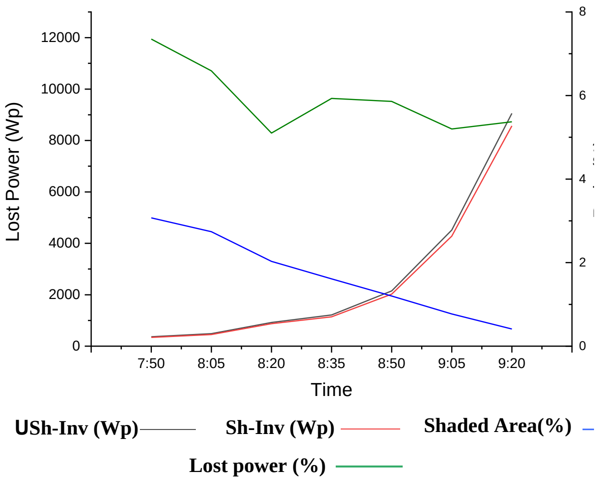

Figure G. Instant production data and ratios for January 30, 2019.

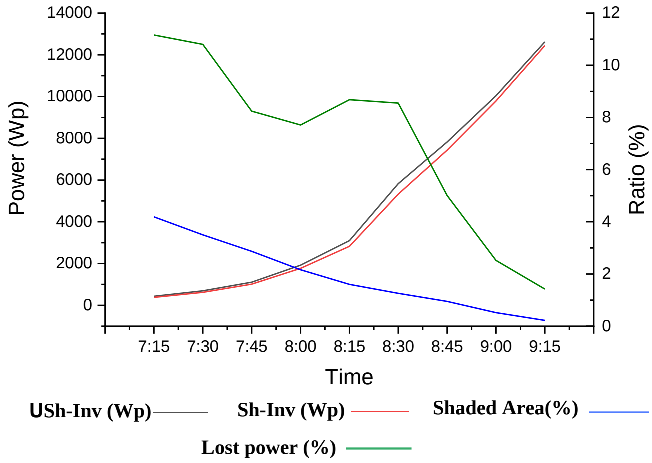

Figure H. Instant production data and ratios for February 27, 2019.

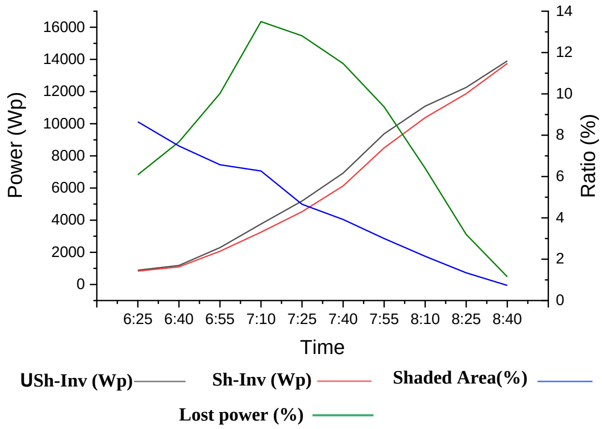

Figure I. Instant production data and for March 28, 2019.

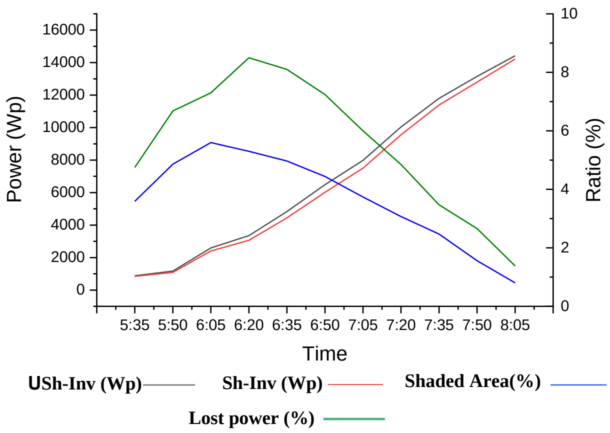

Figure J. Instant production data and ratios for April 30, 2019

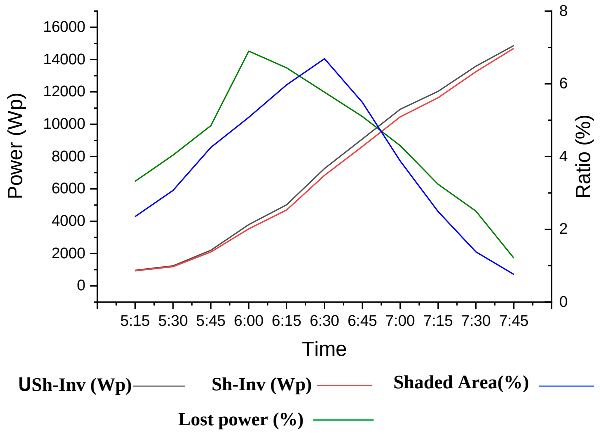

Figure K. Instant production data and ratios for May 29, 2019.