Behavior of Photovoltaic during the Partial Solar Eclipse in Bandung

A B D Nandiyanto*, A Rusli¹, A Purnamasari¹, A G Abdullah² and L S Riza³

¹Departemen Kimia, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi no 229, Bandung 40154, Jawa Barat, Indonesia
²Departemen Pendidikan Teknik Elektro, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi no 229, Bandung 40154, Jawa Barat, Indonesia
³Departemen Ilmu Komputer, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi no 229, Bandung 40154, Jawa Barat, Indonesia

*nandiyanto@upi.edu

Abstract. The purpose of this study was to investigate the behavior of photovoltaic system during the partial solar eclipse phenomenon of 9 March 2016 in Bandung, Indonesia. In the experimental method, we monitored the impact of the solar eclipse on the photovoltaic system in solar cell system. To qualitatively explain the experimental observations, we compared the behavior of photovoltaic system in the solar eclipse day (9 March 2016) with the two sunny days (8 and 10 March 2016). The experimental results showed that the intensity and electricity power increased along with the solar light irradiation time. However, when there is a solar eclipse phenomenon, the intensity and electricity power is suddenly down.

1. Introduction
Photovoltaic system has attracted considerable attention of researchers because this system is one of the best options for solving the energy problems in this era [1,2] the system is potential to generate large energy from renewable energy source. [3]

Many papers have reported several developments of photovoltaic system, including information on strategies for increasing the photovoltaic system efficiency [1], managing the condition of system [4-7], and optimizing the process via model consideration [8]. However, report on the photovoltaic system behavior during the nature phenomenon (such as the solar eclipse event) is typically rare. In fact, nature has its way to control the environmental condition that can modify the process condition.

Based on our previous experience [9,10], here, the purpose of this study was to investigate the behavior of photovoltaic system when facing the partial solar eclipse phenomenon of 9 March 2016 in Bandung Indonesia. To simplify the system, we investigate the photovoltaic energy using a mini solar cell equipment that was completed with a lux meter and connected to the computer system to get real-time measurement analysis. To explain the experimental observation and to ensure the data, we compared the behavior of photovoltaic system in the solar eclipse day (9 March 2016) with the two sunny days (8 and 10 March 2016). We found that the solar eclipse phenomenon has a great impact to control the behavior of the photovoltaic system since this phenomenon create great change in the solar radiation intensity.
2. Hypothetical of partial solar eclipse phenomenon
Solar eclipse is an astronomical phenomenon when the moon obstructs the sun [11,12] (see Figure 1a). During these phases, several phenomena happen, including change in solar intensity [13], light spectrum, and UV irradiation [14,15]. There are three types of solar eclipse: total solar eclipse, annular solar eclipse, and partial solar eclipse, in which this depends on the umbra and penumbra region. Detailed information regarding the solar eclipse is described in elsewhere [5].

In short, regarding the partial solar eclipse (see Figure 1b), several phases happen:
(i) The first contact. The edge of the Moon starts to cover the edge of the Sun.
(ii) The second contact. Almost the entire Sun is masked by the Moon.
(iii) The maximum eclipse phase. The Moon’s cover is in the maximum condition, or the distance between the center of the Sun’s disc and the Moon’s disc is minimum.
(iv) The third contact. The Moon starts to move from the Sun, and the intensity start to increase.
(v) The fourth contact. The Moon stops to cover the Sun, and this phase knows as the end of solar eclipse.

![Figure 1](http://www.eclipsegeeks.com/and https://www.britannica.com/topic/partial-phase/images-videos/Successive-phases-of-a-total-and-a-partial-solar-eclipse/1224, respectively.)

3. Experimental Method
The experiment was carried out at the experimental field of the Universitas Pendidikan Indonesia (6.86340 SL, 107.59430 EL) in Bandung, Indonesia on 9 March 9 2016 (See Figure 2). As shown in Figure 2, the site was selected because it was thorough the path of the solar eclipse (about 88.76%). The day of the eclipse was characterized by mostly clear skies, with some light cloud, slight westerly winds, and comparatively low pollution.
The photovoltaic system used for the measurement was completed with a mini solar cell (3V, 0.42 Watt, Guangzhou Future Solar Technology Co. Ltd., China) with sizes of 54 x 54 x 30 mm. To ensure the effect solar irradiation on the photovoltaic system, we also analyzed the solar radiation intensity using a lux meter (BH1750FVI, Rohm Co. Ltd., Japan). All systems, including solar cell and lux meter, were connected to the computer system via a low-cost and open-source I/O board (Arduino UNO). Since the solar eclipse held in the morning, the solar intensity and the PV system were oriented to be perpendicular to the ground to get the maximum adsorption of solar energy.

![Path of the solar eclipse over Indonesia on March 9, 2016. The field site was located at Universitas Pendidikan Indonesia, Bandung, about 550 km from the central axis of the eclipse totality, and experienced an 88.76% eclipse at 07:21 local time (LT) (00:21 Universal Time (UT)). The path of solar eclipse was adopted from https://www.timeanddate.com/eclipse/solar/2016-march-9. The magnified map was adopted from http://www.reisgidsindonesie.com/Gebied/West-Java.](image)

4. Results and Discussion

**Figure 3a** shows the photograph image of the sun during the maximum phase. We found that the Sun was red and crescent shape by the camera. This shape confirm that the moon obstacles the sun light (see **Figure 3b**). The totality of the dark was not observed because Bandung experienced the partial solar eclipse phenomenon. [9,10]

**Figure 4** depicts a time series of instantaneous output power during three sunny days (from 8 to 10 March 2016) between near to sunrise (06:00 am) and morning (09:00 am). The results showed the same trends with the solar radiation in each phases during the solar eclipse. As shown in the figure, the usual sunny day (i.e. 8 and 10 March 2016) provided the maximum electricity easily. The power increased from about 2 to the maximum electricity (3 mV). The power was detected from 2 mV because the solar intensity at 06:00 am for these three days was about 300 lux. The rate of increasing power in the usual days is about 0.033 mV/min. However, when there is a partial solar eclipse, the rate of increasing power decreased down to about 0.0058 mV/min.
Based on the phases happening during the solar eclipse, we divided the phase into the five zones:
(1) Before the partial phase I (06:00-06:20 am), the rate was similar to that in the sunny days.
(2) In the partial phase I (06:20-07:21 am), the increase in the power was parabolic, in which the power
near to the maximum phase decreased.
(3) In the case of maximum eclipse phase (07:21-07:23 am), the rate decreased. Interestingly, the
instantaneous power was about 18% in comparison to the value from the usual sunny day, which was in
a good agreement to the coverage area of the sun (12%).
(4) When the partial phase II (07:23-08:32 am) occurred, the rate increased. The power gets near to the
usual days (8 and 9 March 2016) at 08:00 am.
(5) After the partial phase II (after 08:32 am), the power was similar to that in the usual days (8 and 10
March 2016).

Figure 3. Photograph image of the sun during the maximum phase (a) and its illustration model of the
moon’s coverage on the sun (b).

Figure 4. Profile of power gained from photovoltaic system during the solar eclipse day (9 March
2016) and two sunny days (8 and 10 March 2016). LT is local time.
To confirm the result from the photovoltaic system, we adopted result from Nandiyanto et al, as shown in Figure 5. The results showed that solar radiation increased along with the increasing time from sunrise to morning. In the case of 8 and 10 March 2016, the intensities increased from 300 to 45,000 lux with a rate of 1,200 lux/min. However, for the case of 9 March 2016 (solar eclipse day), the rate was relatively slower than that of 8 and 10 March 2016. The radiation intensity decreased because the blockage area of the Sun by the Moon’s disc during the solar eclipse. When the maximum eclipse phase happen with regard to the intensity of sunny day that was more than 60,000 lux investigated in 8 and 10 March 2016, the intensity (observed about 10,000 lux) during the solar eclipse was in a good agreement with the blocking area of the sun by the moon. The ratio intensity was at least 16%, whereas the shinning area of solar was about 12%. This intensity result confirmed the result of power in Figure 4 that discussed about the decrease in the maximum power during the maximum solar eclipse.

![Figure 5. Profile of solar radiation in 8, 9, and 10 March 2015 from 06:00 to 09:00 LT. Figure was taken from reference (Nandiyanto et al 2016)](image)

5. Conclusion
We have successfully investigated the behavior of photovoltaic system when facing the partial solar eclipse phenomenon of 9 March 2016 in Bandung, Indonesia using a mini solar cell equipment that was completed with lux meter and connected to the computer system to get real-time measurement analysis. Compared to the behavior of photovoltaic system in two sunny days (8 and 10 March 2016), we found that the solar eclipse phenomenon has a great impact to control the behavior of the photovoltaic system since this phenomenon create great change in the solar radiation intensity.
Acknowledgements

We acknowledged RISTEKDIKTI (Grant: Program Unggulan Perguruan Tinggi (PUPT)) and Sekolah Pasca Sarjana Universitas Pendidikan Indonesia (Grant: Penelitian Lintas Disiplin). We thank to Andi Muhlis and Dr. Tutin Ariyanti for their help in taking solar eclipse photograph picture.

References

[1] Tsengenes G and Adamidis G 2011 Investigation of the behavior of a three phase grid-connected photovoltaic system to control active and reactive power Electri Pow Syst Res 81(1), 177-184.

[2] Dincer F 2011 The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy Renew Sust Energy Rev 15(1) 713-720

[3] Reda I 2015 Solar eclipse monitoring for solar energy applications Solar Energy 112 339-350.

[4] Kobayashi K, Takano I and Sawada Y 2006 A study of a two stage maximum power point tracking control of a photovoltaic system under partially shaded insolation conditions Sol Energy MatSol C 90(18) 2975-2988

[5] Hua C, Lin J and Shen C 1998 Implementation of a DSP-controlled photovoltaic system with peak power tracking IEEE Trans Industrial Electronics 45(1) 99-107.

[6] Kim I S, Kim M B and Youn M J 2006. New maximum power point tracker using sliding-mode observer for estimation of solar array current in the grid-connected photovoltaic system IEEE Trans Industrial Electronics 53(4) 1027-1035

[7] Kofinas P, Dounis A I, Papadakis G and Assimakopoulos M N 2015 An Intelligent MPPT controller based on direct neural control for partially shaded PV system Energ Build 90 51-64

[8] Wang Y J and Sheu R L 2015 Probabilistic modeling of partial shading of photovoltaic arrays Int J Photoenergy 2015

[9] Haristiani, N, Wirayanti A S, Rusli A, Nandiyyanto, A B D, Widiyat A G A, & Ana R H 2016 Did the Solar Eclipse of 9 March 2016 Attract Tourist to Come to Indonesia? Proceeding of Asia Tourism Forum 2016 – The 12th Biennial Conference of Hospitality and Tourism Industry in Asia (ATF-16), 432-26

[10] Nandiyyanto A B D, Sofiani D, Permatasari N, Sucahaya T N, Wirayanti A S, Purnamasari A, Rusli A and Prima E C 2016 Photodecomposition Profile of Organic Material during the Partial Solar Eclipse of 9 March 2016 and Its Correlation with Organic Material Concentration and Photocatalyst Amount Indonesian J Sci Technol 1(2) 132-155

[11] Fabian P, Winterhalter M, Rappenglück B, Reitmayer H, Stohl A, Koepke P, Schlager H, Berresheim H, Foken T and Wichura B 2000 The BAYSOFI Campaign – Measurements carried out during the total solar eclipse of August 11, 1999 Meteorol Z 10(3) 165-170

[12] Nishanth T, Ojha N, Kumar M S and Naja M 2011 Influence of solar eclipse of 15 January 2010 on surface ozone Atmos Environ 45(9) 1752-1758

[13] Cowsik R, Singh J, Saxena A K, Srinivasan R and Raveendran A V 1999 Short-period intensity oscillations in the solar corona observed during the total solar eclipse of 26 February 1998 Sol Phys 188(1) 89-98

[14] Zerefos C S, Balis D S, Zanis P, Meleti C, Bais A F, Tourpali K and Papayannis A 2001 Changes in surface UV solar irradiance and ozone over the Balkans during the eclipse of August11, 1999 Adv Space Res 27(12) 1955-1963

[15] Tzanis C, Varotsos C and Viras L 2008 Impacts of the solar eclipse of 29 March 2006 on the surface ozone concentration, the solar ultraviolet radiation and the meteorological parameters at Athens, Greece Atmos Chem Phys 8(2), 425-430