Quantifying Soiling Accumulation on Photovoltaic Modules Using Standard Testing Results

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Abstract

Quantifying soiling accumulation on PV modules installed in the field can be determined by using standard laboratory testing results of short circuit current (Isc) and temperature coefficients. Soiling accumulation on PV modules affects to attenuate optical transmission to solar cells that is represented by reduction of Isc. Two c-Si PV modules were selected to present. The two PV modules were installed for a period of six months in outdoor conditions. The data of Isc were collected and then corrected different performances by using measurement results from the laboratory. All data were converted and normalized to data at STC condition by using Isc at STC and temperature coefficient of Isc. It is found that soiling accumulation was 8.8% at maximum values. Increasing of soiling accumulation was 6.6% for a period of 42 days with no rainy day. In this paper, it is found that the rate of increasing soiling accumulation on clean glass is higher than on soiled glass. For the clean glass module, soiling accumulation was 0.71%, but the soiled glass was 0.31%, in the same 15-days period. The results of power loss, due to soiling accumulation, of a PV system installed beside the experiment were also reported. The system Power loss was 7.11%, but Isc reduction of module was 6.25% for a period of 34 days with no rainy day.

Keywords: PV Modules; Soiling Accumulation; Dust Deposition; Soiling Loss

1. Introduction

The total installed capacity of global PV systems has been rapidly growth from 20.4 GW in 2009 to 627 GW at the end of 2019. Although the growth of large China markets tends to be declined from 53.0 GW, 43.4 GW and 30.1 GW in 2017, 2018 and 2019 respectively. Outside of China, the global PV markets increased from 58.8 GW in 2018 to at least 84.9 GW in 2019, accounted 44% of growing, which 10 leading PV accumulated installation countries in 2019 were China, India, Japan, Vietnam, Australia, Korea, Spain,

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Germany, Ukraine and USA. However, 60% of global PV capacity was in Asia pacific countries [1-2]. As the same way, Thailand has increased the amount of PV installation similarly with global market. As 2006, the installed capacity was around 1.1 MW, following by 3250 MW in 2018 within 20 years. Furthermore, the government had announced Power Development Plan, PDP2018 which targeted the total PV installation to be 12725 MW within 2030 [3].

According to IEC 61724-1:2016, it has PV efficiency evaluation standard which indicates the environmental factors effected PV system efficiency, including PV module temperature, ambient air temperature, wind speed and direction, rainfall, snow, and humidity. Moreover, soiling is another crucial factor which also affects PV system efficiency. (IEC61724-1).

Many researchers, summarized in Table 1, studied on the effects of dust on performance of photovoltaic, such as The Hong Kong Polytechnic University in China, the experiment was designed and conducted in the laboratory with a sun simulator and a test chamber. The results indicated that dust pollution has a significant impact on PV module output. As per dust deposition density increasing from 0 to 22 g/m^2, the corresponding reduction of PV output efficiency rises from 0 to 26% [3]. As per Institute of Engineering, Tribhuvan University, Lalitpur in Nepal, the results during 5 months of studying period shows that the efficiency of dusty solar module covering with natural dust deposition phenomena decrease by 29.76% with respect to the module which was cleaned on daily basis. Moreover, dust deposition density on the PV module accounted to 9.6711 g/m^2 over the study period [4]. Seasonal effects of dust on the degradation of PV modules deployed in two locations which have different seasons namely Perth, Western Australia and Nusa Tenggara Timur (NTT), Indonesia. The results of total Pmax losses for the modules deployed at Australia ranging from 6 to 8% and from 16 to 19% for modules at Indonesia. These losses were mostly contributed by dust in which about 65-72% and 73-81% of the total power degradation of PV panels at Australia and Indonesia respectively [5]. In addition, Renewable Laboratory of Shahid Beheshty University in Iran indicates that, after 70 days without rain, 6.0986 g/m^2 of dust was accumulated on the surface which caused 21.47% reduction in the power output [6]. University of Sharjah, UAE, the results of the indoor experiments revealed a linear relationship between dust density and normalized PV power with a drop of 1.7% per g/m^2. As well as the outdoor experiments showed that the soiling loss increased by 12.7% while the dust density increased by 5.44 g/m^2 for a period over 5 months [7].

There is an experimentation of dust on performance of photovoltaic such as Sohar University in Oman, the experimental analysis of the effect of dust's physical properties from 6 cities on photovoltaic modules. The differences in physical properties of dust affects PV module performance, a higher moisture leading to the most PV module performance reduction. The results show a 35–40% reduction in PV module power production [8]. Environment and Sustainability Institute (ESI), United Kingdom, studied the effect of accumulation of 13 different types of dust on PV performance. The results show that charcoal appears to have the worst degradation effect on PV performance with about 98% reduction in short circuit current while salt seems to have the least impact with about 7% [9]. University of Technology, Iraq, studies 5 different building materials. The results show that gypsum causes the most power reduction when the accumulation is more than 25 g/m^2 and the power reduction rate is about 12-14 % in 3 months [10]. Lahore University of Management Sciences, Lahore, Pakistan studies of power output losses and dust accumulation on solar panels which were measured at variable tilt angles. The average daily output power losses due to soiling for mono-facial PV panels ranges from 1.11% (at the tilt of 0^o) to ~0.11% (at the tilt of 90^o) [11].

In Thailand, the effects of dust accumulation on performance ratio between solar rooftop system and solar power plants are also studied that the results in period 1-month performance ratio decreases about 1.6-3% and another 6-8% decrease with increased dust accumulation by 2-months. The research analysis method is to focus on the effects of dust accumulation on performance ratio using the cleaning methods to compare between clean device and soiled device which experimental results appeared during the dry seasons [12]. Therefore, power loss due to soiling accumulation is interested to study for PV power plants with high incentive rate. It is essential to plan the cleaning schedule, cost and earned benefits. According to the dust accumulation investigation, there can be divided into 2 types of study which are field and laboratory consideration. However, researcher realized that there previously has the effective dust accumulated information from PV system which sparks the attention on the study by using the field data, outdoor condition, and temperature coefficients from standard testing laboratory in order to adjust the value of short circuit current (Isc) for field, outdoor condition.

This work focuses on quantifying soiling accumulation on PV modules by using values of short circuit current (Isc) and temperature coefficients from a standard testing laboratory. The measurement of all modules in testing laboratory were done in prior to install in the outdoor experiment. The attenuation of optical transmission can precisely be determined by the ratio of Isc of soiled module to Isc of clean module. PV modules in this study were installed in outdoor conditions during dry season. The comparison of power loss due to soiling accumulation of a PV systems and the reduction of Isc were also studied.

2. Methodology

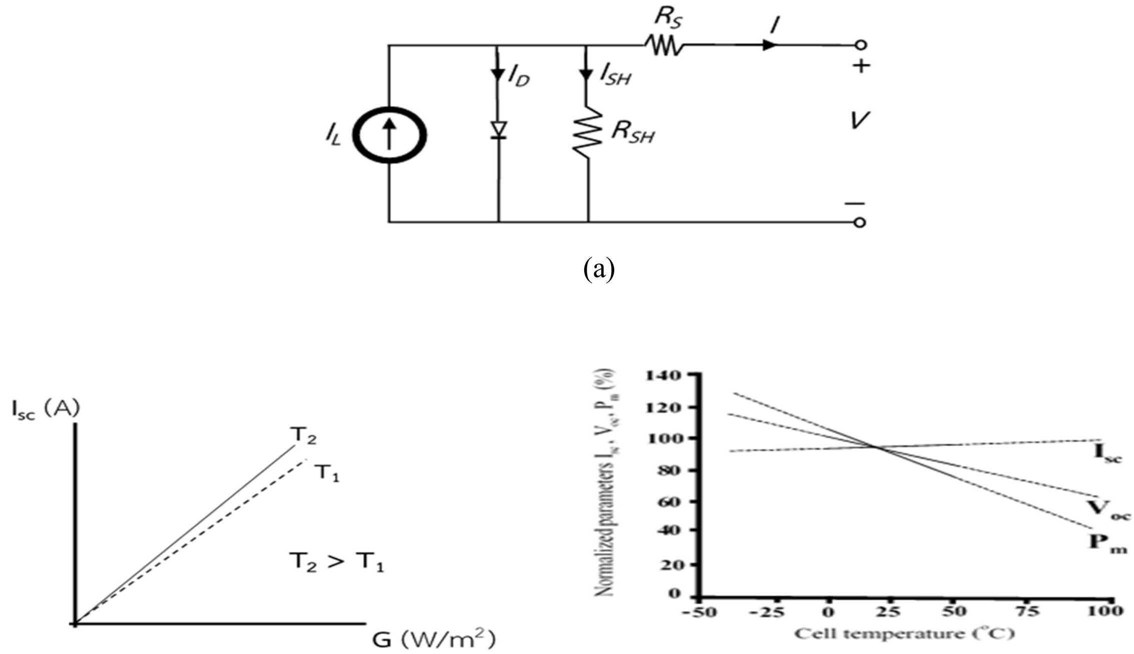
This investigation focuses on soiling accumulation on PV modules for the period of six months, September 2019 – February 2020. The site location is, at 13°34′ North latitude and 100°26′ East longitude, on the southern of Bangkok, Thailand. The ambient temperature is 28.1 °C in Bangkok. The Bang Khun Thian District of Bangkok lie on 1-1.5 m above sea level. The annual precipitation fall is about 1430 mm. Annually, dry season in the country is in between November and February which is the winter. The average solar irradiation is around 5.24 kWh/m^2/day (http://www.dede.go.th/, 2017). Modules, in operation for many years, can be ensured the stabilized condition or to avoid the initial degradation. Each module was measured the performance at STC and the temperature coefficient measurement according to IEC61215:2005 by an accreditation testing laboratory according to ISO/IEC17025.

Table 1 Summary of investigations of soiling effects on PV systems

Ref.	Period of study	Location	dust density	decreases rates	method
[4]	5 months	Nepal	9.6711 g/m^2	29.76%	field
[5]	1 year	Australia Indonesia	0.17 mg/cm^2 0.37 mg/cm^2	6-8% 16-19%	field
[6]	70 days	Iran	6.0986 g/m^2	21.47%	field
[7]	5 months	UAE	5.44 g/m^2	37.63% (tilt 0^o) 14.11% (tilt 25^o) 10.95 % (tilt 45^o)	laboratory
[8]	3 months	Iraq	-	35-40%	laboratory
[9]	-	United Kingdom	-	7%	laboratory
[10]	3 months	Iraq	25 g/m^2	12 – 14%	laboratory
[11]	2 months	Pakistan		1.11% (tilt 0^o) 0.11% (tilt 90^o)	laboratory
[12]	2 months	Thailand	-	6-8%	field
[13]	1 month	Bangladesh	-	26%	field
[14]	6 months	Saudi Arabia	6.184 g/m^2	50%	field
[15]	1 year	Hong Kong	22 g/m^2	26%	laboratory
[16]	8 months	Cyprus	-	6-13%	field
[17]	5 months	Qatar	-	30%	field
[18]	1 month	Pakistan	4.6 g/m^2	16.16% (mono-PV) 11.54 % (poly-PV)	field

The data for analysis were mainly come from 3 parts consisting of the results, from the standard testing laboratory, short circuit current (Isc) of each module in outdoor condition, and a small PV grid-connected system. Soiling accumulation on PV modules during each period in the dry season was observed. The comparison for the soiling increased rate between soiling on the glass and soiling on the soiled glass was highlighted.

By the principle of solar cell as shown in Fig. 1, the short circuit current (Isc) of a solar cell is directly proportion with incident solar irradiance. It means that the effects of soiling accumulation on PV modules can directly be determined by the reduction of short circuit current. Transmission of solar irradiance onto cells in a module will be attenuated by soiling or dust on the glass of module.



(a)

(b) (c)

Fig. 1 Equivalent circuit of a solar cell and principle of its short circuit current

(a) Equivalent circuit of a solar cell

(b) Principle of short circuit current of a solar cell

(c) Electrical parameters and their temperature dependence

As per the experiment, there were many pairs of modules, as same model, in comparison. In this paper, the mono crystalline was firstly selected to present in this paper. The specification of each PV module is mono-crystalline silicon 75 Wp, short circuit current (Isc) 4.80 A, current at maximum power (Imp) 4.40 A, open circuit voltage (Voc) 21.40 V, voltage at maximum power (Vmp) 17.00 V, and fill factor (FF) 0.72.

2.1 Measurement of PV modules in the standard testing laboratory

To ensure the actual module performance in prior to the outdoor experiment, each module was taken to the standard testing laboratory, according to ISO/IEC17025 accreditation. The measurement of performance at standard test condition (STC) was performed according to IEC61215:2005 clause 10.6 and IEC60904-1. The measurement of temperature coefficients was performed according to IEC61215:2005 clause 10.4, respectively. Temperature coefficients consist of temperature coefficient of short circuit current (α), temperature coefficients of open circuit voltage (β) and temperature coefficients of maximum power (δ), were obtained results from the standard testing laboratory. Electrical parameters, consisting of current-voltage characteristic (I-V curve), short-circuit current (Isc), open-circuit voltage (Voc), current at maximum power point (Im), voltage at maximum power point (Vm), power at maximum power point (Pm), fill factor (FF), were obtained from solar simulator set in measurement of performance at STC.

The uncertainty of measurement for performance at STC is 2.24% that is given by the laboratory. The measurement was done by the Pasan solar simulator IIIb with class AAA in accordance with IEC60904-9.

2.2 Quantifying soiling accumulation on PV modules using short circuit current

Each pair, with the same model, of PV modules were exposed in the outdoor condition. PV modules were installed on the free-standing rack mount structure, with tilt angle 14 degree facing to the south, on the flat roof of a building as shown in Fig.2. All PV modules, in prior to this experiment, were measured electrical performance parameters at STC, and temperature coefficients, from the standard testing laboratory, as described in the section 2.1. In this paper, the results of two mono-crystalline Silicon PV modules were focused. One PV module is called the clean module (PV11), and another PV module is called the soiled module (PV12). Firstly, both modules were completely cleaned, then the soiled module was not cleaned until the end of experiment. The clean module was completely cleaned at any periods of time when we would like to determine the soiling accumulation on the soiled module. The measuring data consisting of in-plane solar irradiance, ambient temperature and humidity, and module temperature, were collected in once a minute. The data were taken by the measuring instrument as listed in Table 2. The calculation and data filtering were manipulated by using php coding in parallel with Microsoft Excel. By the reason of response time difference between thermopile pyranometer and short circuit of modules measurement, it is necessity to do data filtering and data selection.

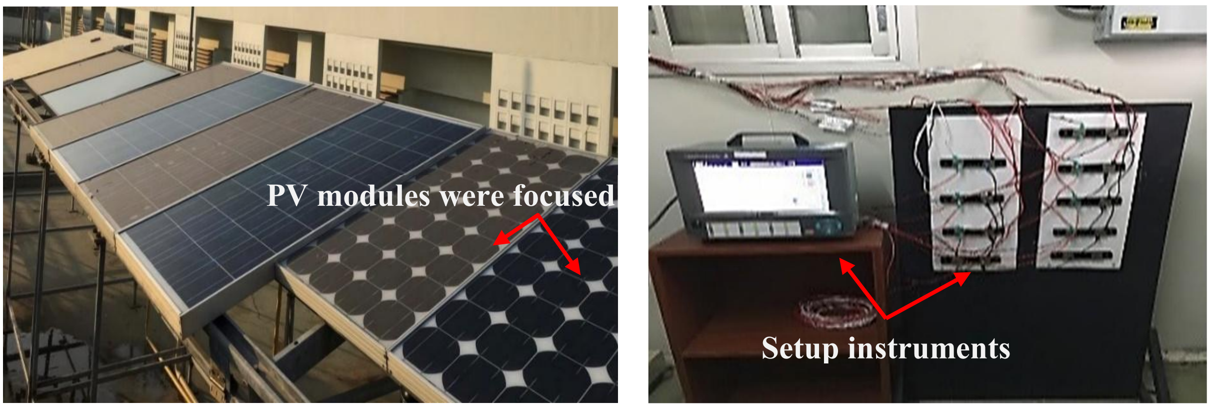


Fig. 2 PV modules installation

Table 2 List of instruments for outdoor measurement

Measurement Item	Instrument
Data Logger	Yokogawa DX2020
Solar Irradiance	Pyranometer CM11 Kipp & Zonen
Module Temperature	Thermocouple Type T
Short circuit current of each module	Shunt resistor (10A/75mV)

In comparison, the different performance of Isc of two modules are corrected and verified by two methods. One is corrected by the ratio, called R_{lab}, of Isc at STC obtained from the laboratory results in section 2.1. Another method is corrected by using the ratio, called $R_{outdoor}$, of slopes of Isc versus G on the first or earlier day after installation which was not the cloudy day as shown in Fig.3.

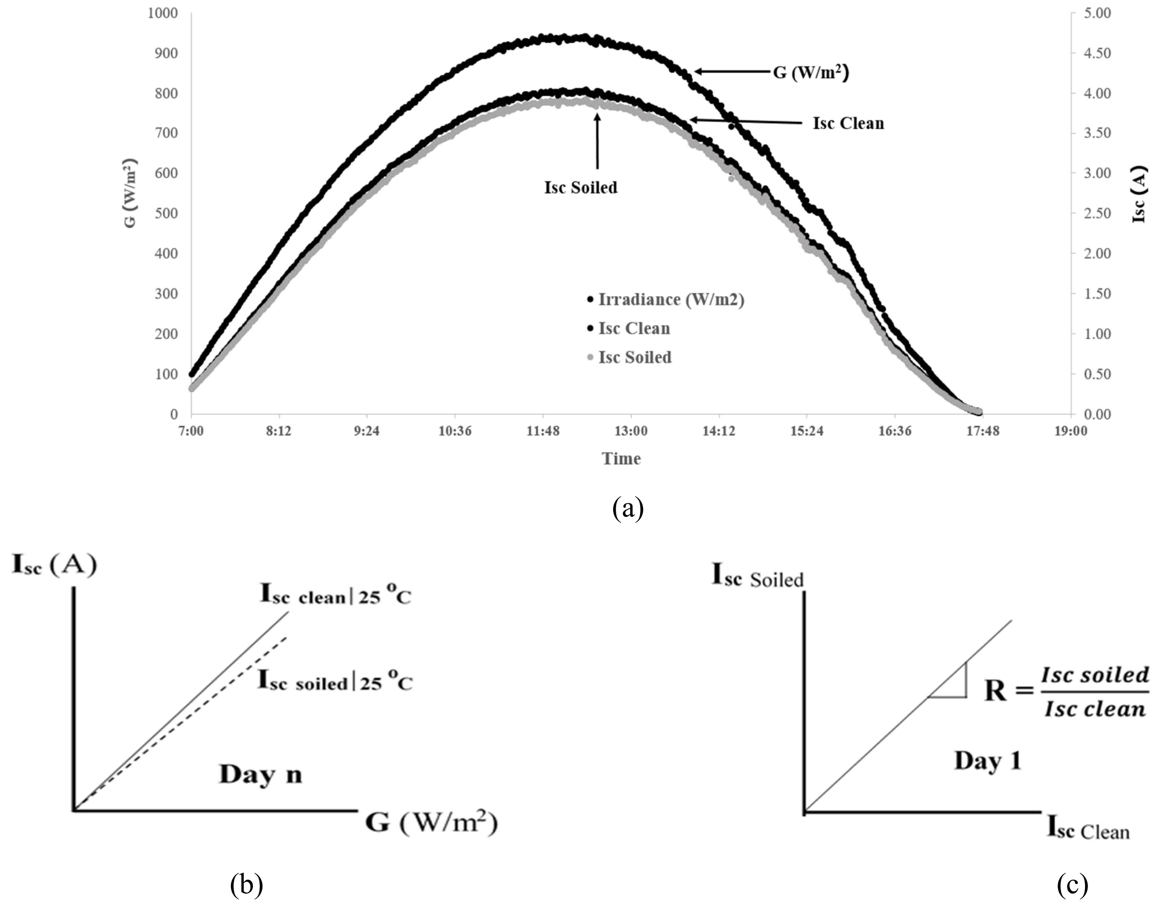


Fig. 3 (a), (b) and (c) Outdoor method to correct the different performance of two modules

(a) daily profiles of irradiance, Isc (PV11), Isc (PV12)

(b) Isc (PV11) and Isc (PV12) versus irradiance

(c) Isc (PV12) versus Isc (PV11)

Data of short circuit current (Isc) at any irradiance can be converted to Isc at STC, at 1000 W/m^2 and module temperature at 25°C, by using data of in-plane solar irradiance (G) and module temperature (T_m) as Eq. (1). Daily slope of *Isc* versus *G* can be calculated by linear regression as Eq. (2).

$$Isc_{/at\ 25^oC} = Isc_{/at\ T}\,(1+\alpha(T_m - 25)) \quad (1)$$

Where $Isc_{/at\ T}$ and T_m are short circuit current and module temperature values were obtained by measurement at a particular time, α is the temperature coefficient of short circuit current from the standard testing laboratory (0.03%/°C).

$$slope\ of\ Isc = \frac{\sum_{i=1}^{n} G_i^2 \cdot \sum_{i=1}^{n} I_{sc_i}^2 - \sum_{i=1}^{n} G_i \sum_{i=1}^{n} G_i I_{sc_i}}{n\sum_{i=1}^{n} G_i^2 - \left(\sum_{i=1}^{n} G_i\right)^2} \quad (2)$$

Where G_i and I_{sc_i} are in-plane solar irradiance and short circuit current values were obtained by measurement at a particular time.

When the clean module (PV11) was cleaned at the day-n, the effect of soiling accumulation can be determined by using the reduction of Isc with correction and converted to Isc at STC condition as shown in Fig. 4

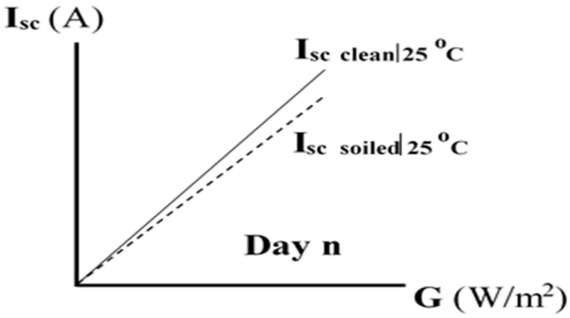


Fig. 4 Reduction of Isc due to soiling accumulation

2.3 Soiling accumulation on PV modules in a PV system

There was an existing small PV grid-connected system installed beside the experiment set in the section 2.2. PV modules in the system, as same as tilt angle of the above experiment, were put into operation since 2003, while the measuring equipment were well set up in 2010. The data consisting of in-plane solar irradiance, ambient temperature and humidity, wind data and module temperature, were collected in once a minute. In this paper, we only analyze the values of dataset of system in some days such as rainy days. The data of DC power were converted to 1000 W/m^2 and 25°C or at STC condition, by using temperature coefficient of maximum power (δ), at the day after cleaning date. Data filtering and elimination of other losses were done in short term evaluation. The values of power loss due to soiling accumulation were compared with the reduction of Isc of PV12 or the soiled module in the previous section.

3. Results and discussion

Results in this study mainly can be divided into 3 parts consisting of performance measurement of PV modules from standard testing laboratory, data set of short circuit current (Isc) of each pair of PV modules for the period of six months, and data from the existing PV system. Experiments were set up at

King Mongkut's University of Technology Thonburi (KMUTT), Bang Khun Thian Campus. For the results of short circuit current, the two monocrystalline silicon PV modules, with the same model, were selected to report in this paper.

3.1 Results from standard testing laboratory

All PV modules were measured and presented in 2 test items consisting of performance at standard test condition (STC) and temperature coefficients according to clause 10.6 and clause 10.4 of IEC61215:2005 detailed in the section 2.1. The testing results were done by a standard testing laboratory according to ISO/IEC17025 accreditation. The testing results were shown in Table 3. The values of short circuit current (Isc) and temperature coefficients of short circuit current (α) were used in the section 3.2. For Module No. PV11, the measured Isc at STC is 92.29% of its nameplate, but the measured Isc at STC of Module No. PV12 is 91.25% of its nameplate, respectively. Module No. PV11 is called the clean module, and PV12 is called the soiled module in the section 3.2. The different values of Isc at STC of both modules can be corrected by the ratio of Isc at STC. The ratio of Isc at STC of PV12 to I_{sc} at STC of PV11 is called R_{lab}. From the results, the ratio, R_{lab}, is 1.011. The correction factor or R_{lab} will be used to compensate the data of Isc obtained by the outdoor data collection of both modules. The data of Isc from the outdoor experiments will be converted to 1000 W/m^2 and 25°C or at STC condition by using in-plane solar irradiance and value of temperature coefficient of Isc (α) of each module.

Table 3 Parameters obtained by measurement of performance at standard test condition (STC) and measurement of temperature coefficients

Parameters \ **PV modules**	**UNIT**	**PV12**	**PV11**
Maximum Power (P_{max})	W	59.20	61.70
Open Circuit Voltage (V_{oc})	V	21.60	21.70
Maximum Power Voltage (V_{mp})	V	15.70	15.70
Short Circuit Current (I_{sc})	A	4.38	4.43
Maximum Power Current (I_{mp})	A	3.77	3.92
Fill Factor (FF)	%	62.50	64.20
Temperature Coefficient of short circuit current (α)	%/°C	0.03	0.03
Temperature Coefficient of open circuit voltage (β)	%/°C	-0.36	-0.35
Temperature Coefficient of maximum power (δ)	%/°C	-0.60	-0.54

3.2 Results of quantifying soiling accumulation using values of Isc

In this section, all values of current are short circuit current value or Isc of modules. Two monocrystalline Si PV modules were selected to report in this paper. Both modules having laboratory results, PV11 and PV12, were exposed in the outdoor condition for a period of six months, during 1st September 2019 and 29th February 2020. Both modules were completely cleaned as the initial condition of the experiment. The data consisting of Isc, in-plane solar irradiance, module temperature and ambient temperature were collected in once a minute. The recoding raw data of Isc of each module were corrected or compensated with R_{lab} and converted to STC condition by using irradiance (G) and each module temperature coefficient of Isc (α). Data processing and data filtering were also done. Module No. PV12 was not cleaned until end of the experiment. Module No. PV11 was frequently cleaned for quantifying soiling accumulation of Module No. PV12.

Results of Isc, with correction ratio and converted to 1000 W/m^2 and 25°C condition or at STC condition, were plotted in Fig. 5. Dashed line shows the day with rainfall. Dash-dotted line shows the day which module cleaning. The reduction of transmission to PV cells, due to soiling accumulation or dust deposition on its glass, can be evaluated by the reduction of Isc. The ratio of Isc of PV12 to PV11 can be plotted in Fig. 6.

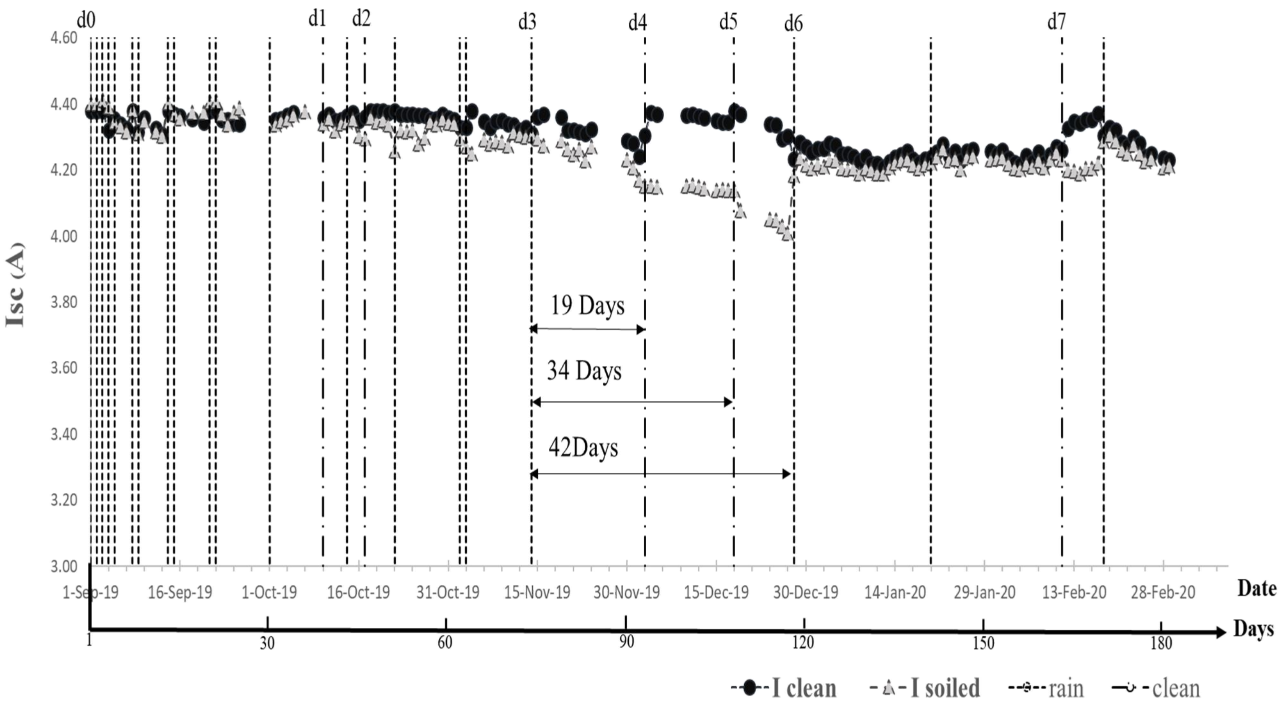


Fig. 5 Isc of both modules corrected with R_{lab} and converted to 1000 W/m^2 and 25°C

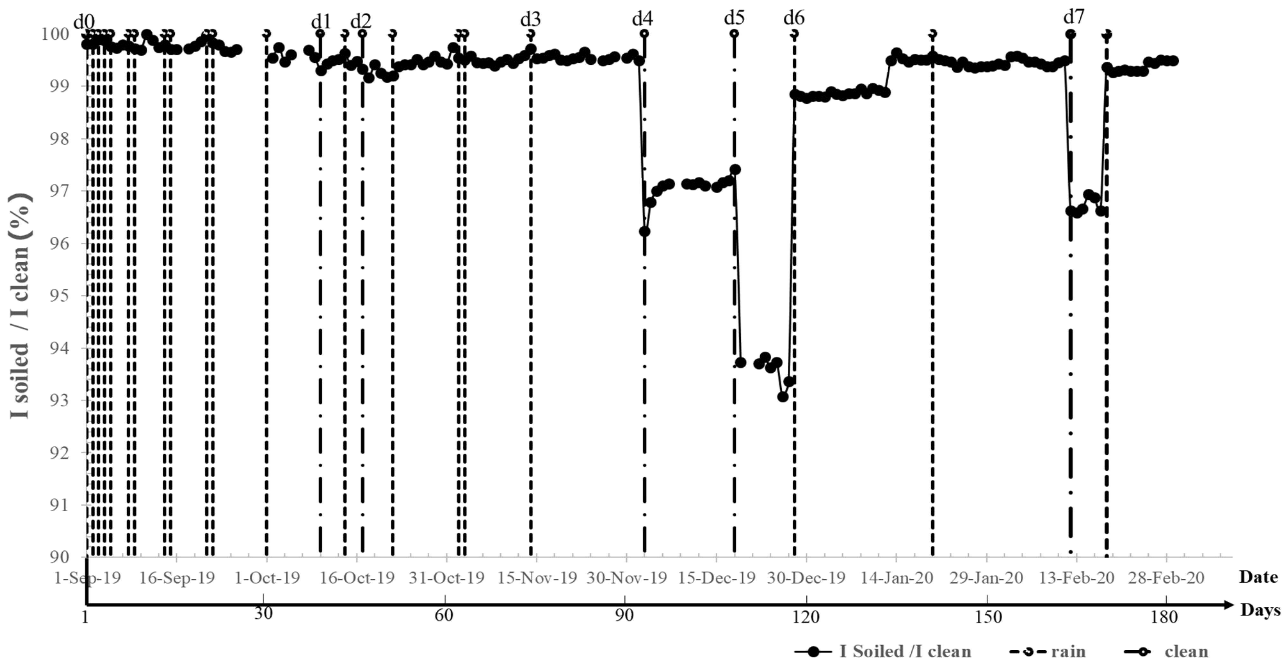


Fig. 6 Ratio of Isc of soiled module (PV12) to the clean module (PV11) with R_{lab} and converted to STC condition

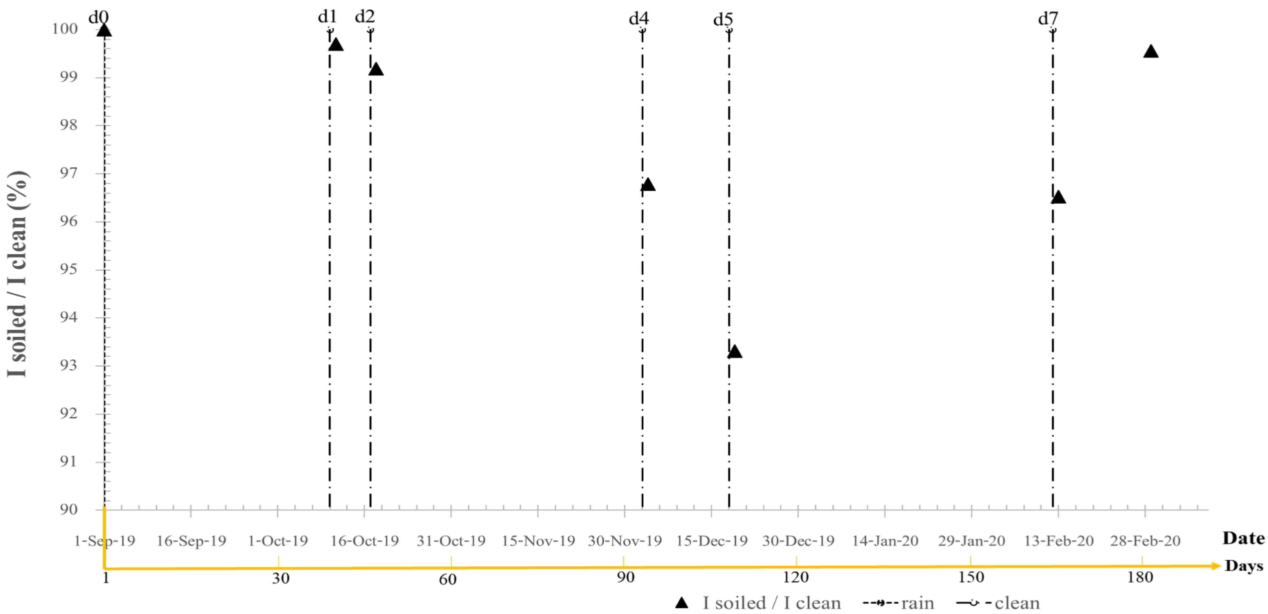


Fig. 7 Profile of soiling accumulation quantifying by the ratio of short circuit current

Table 4 List of cleaning dates of Module No. PV11

List of Date	Date of module cleaning	Ratio after cleaning (Isoiled / Iclean)
d1	10-Oct-2019	0.9943 (0.57%)
d2	17-Oct-2019	0.9916 (0.84%)
d4	3-Dec-2019	0.9680 (3.20%)
d5	18-Dec-2019	0.9375 (6.25%)
d7	12-Feb-2020	0.9658 (3.42%)

The soiling accumulation on module can be determined and quantified by the data of Isc of the day after cleaning the module PV11. From Fig.5, dates, consisting of d1, d2, d4, d5 and d7, are dates of module PV11 cleaning. In the country, it is normally expected the dry season without rainy day beginning in the earlier or the middle of October. From the results, it was found that there was no period of no rain more than two weeks until the middle of November 2019. The longest period with no rain was 42 days between the date d3 (November 14, 2019) and the date d6 (December 28, 2019) as shown in Fig. 5. At the date after d3, both modules were completely cleaned by the rain. At the date after d4 and d5, soiling accumulation was about 3.2% for 19 days and 6.25% for 34 days, respectively. Fig. 9 shows the profile of transmission loss due to soiling accumulation observed on each day after cleaning date.

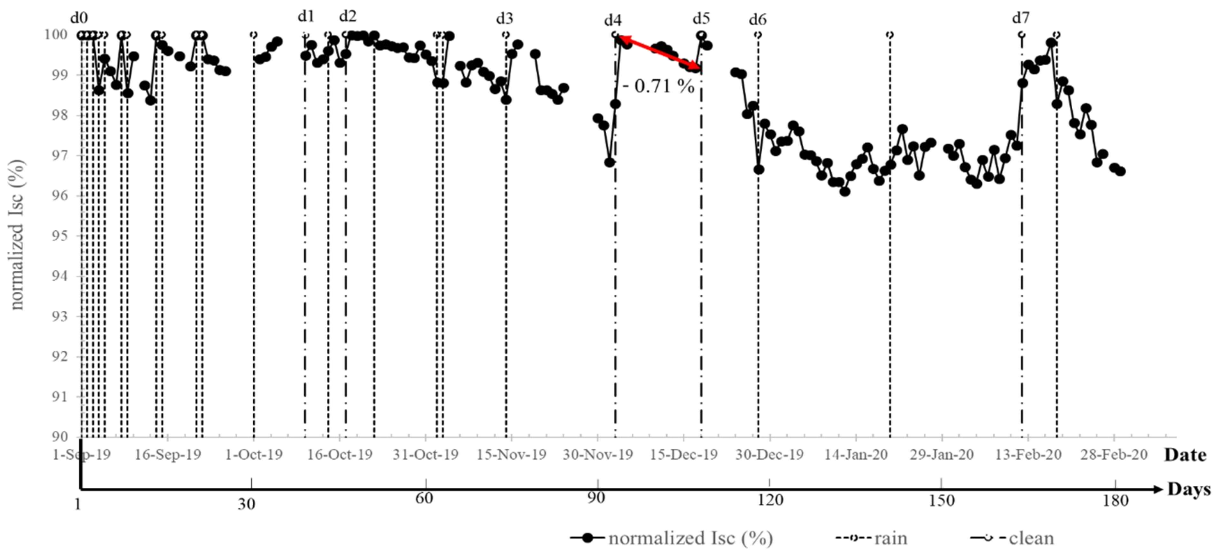


Fig. 8 Short circuit current of Module No. PV11 normalized by Isc at STC from laboratory

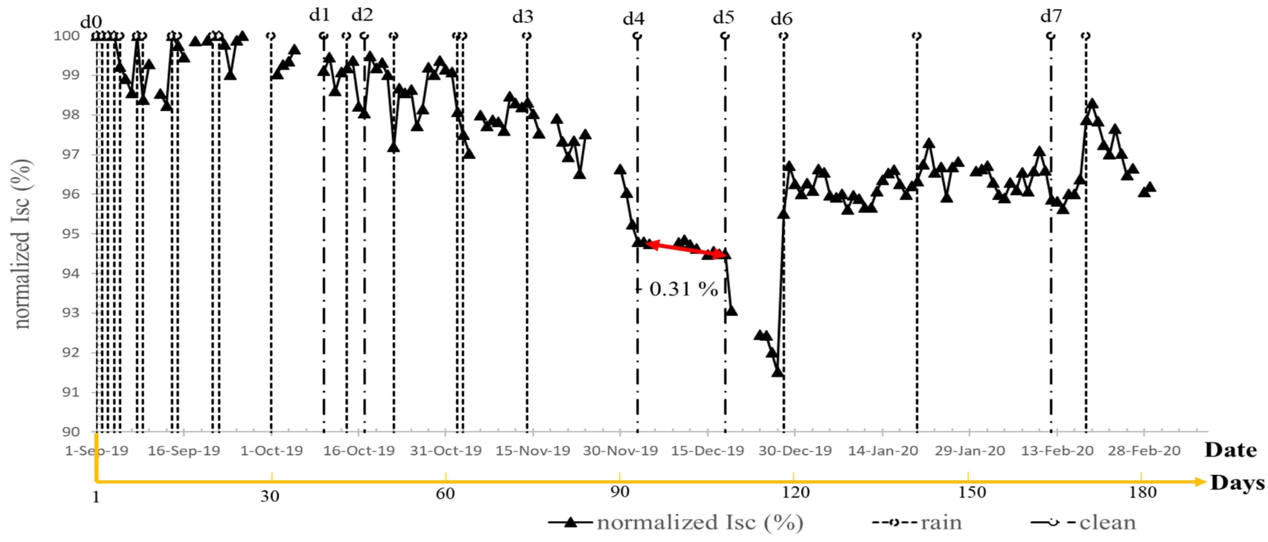


Fig. 9 Short circuit current of Module No. PV12 normalized by Isc at STC from laboratory

The dataset of Isc of each module, from outdoor measurement, can be normalized by its reference value of Isc from laboratory results. The normalized values of Isc can be calculated and plotted in Fig. 8 and Fig. 9. Quantifying soiling accumulation of each module can be done on each day along the period of the study. From the calculated results, transmission loss due to soiling accumulation was 6.63%, between d3 and d6, for the period of 42 days with no rain. In this investigation, the maximum transmission loss due to soiling accumulation was 8.8% at the date d6.

From Fig. 6, it is observed that the ratio of Isc of soiled module, PV12, to Isc of clean module, PV11, after cleaning date. After the date d4, the increasing of ratio was observed in the circle mark. It can be described that the rate of increasing of soiling accumulation or dust deposition on the clean glass is different to the rate of increasing of accumulation on the soiled layer on the glass. It is confirmed by Fig.8 and Fig.9 that reduction of Isc of PV11 was more than reduction of Isc of PV12 during period of 15 days, from d4 to d5. Transmission loss, due to soiling accumulation, of PV11 reduced 0.71% from 0.11% to 0.82%, but PV12 reduced 0.31% from 5.21% to 5.50%. The observation can be described by adhesion force of dust particles on glass, especially in dry condition. Gravity force and electrostatic force were applied. The growth rate of dust deposition of the first layer on glass is more than the growth rate of other layers of dust deposition on top of soiled glass. It can be confirmed by the phenomena in another short period after d1 cleaning date. From the results in this section, it can be summarized that

- The investigation period was 6 months between September 1, 2019 and February 29, 2020. It is focused on periods of days with no rain. Unfortunately, the experiment cannot be continued in the summer dry season, March – April 2020, because of the COVID-19 pandemic lockdown.

- The longest period of no rain, in this study, was 42 days. Transmission loss due to soiling accumulation was 6.63% for a period of 42 days. Quantifying of transmission loss due to soiling accumulation can be described by reduction of Isc in field operation normalized with Isc at STC.

- It is found that increasing rate of soiling accumulation on glass was higher that increasing rate of soiling on the layer of soiled glass.

- Quantifying of soiling accumulation on PV module can be determined by laboratory results consisting of measurement of temperature coefficient of Isc and measurement of performance at standard test condition (at STC). The method is validated by cleaning another module and comparing to the soiled module in the outdoor condition.

3.3 Results of comparison on a PV system

There was an existing PV grid-connected system beside the experiment in the section 3.2. PV modules in the system were put in operation since 2003. In this paper, we only analyze the values of dataset of system in some days such as rainy days. The data of DC power were converted to 1000 W/m^2 and 25°C or at STC condition, by using temperature coefficient of maximum power (δ), at the day after cleaning date as shown the d5 date. At day after d3 date, the values of DC power, converted to STC condition, were completely cleaned by rain as same as the values of DC power at the day after d5 date. The evaluation was 7.1% of power loss due to soiling accumulation, between d3 and d5, for a period of 34 days with no rain. At the same period between d3 and d5, reduction of Isc due to soiling accumulation of module No. PV12 was 6.25%. Quantifying transmission loss due to soiling accumulation on a module may be different to power loss due to soiling accumulation with various parameters such as influences of other losses or gradient of dust deposition on modules or variation of performance of modules in the string. However, the experiment setup to study reduction of Isc due to soiling accumulation was treated more than preliminary observation on soiling loss of the PV system.

4. Conclusions

The reduction of optical transmission of solar cell in a module can be determined by the reduction of the short circuit current or Isc. Quantifying soiling accumulation on a PV module can also be evaluated by the short circuit current. In this paper, the study can be divided into 3 parts consisting of (1) performance measurement by a standard testing laboratory, (2) quantifying soiling accumulation on PV modules using short circuit current, and (3) observation of soiling accumulation on PV modules in a PV system. There were two selected mono-crystalline Si PV modules to describe in this study. Both modules were measured the performance at standard test condition (at STC) and temperature coefficients of short circuit current (α), of open circuit voltage (β) and of maximum power (δ) according to IEC61215:2005 clause.10.6 and 10.4, respectively. Both modules were exposed to outdoor conditions for a period of 6 months between

September 2019 and February 2020. One module (PV11) was called a clean module, and another module (PV12) was called a soiled module. The different performance of Isc was corrected or compensated by the results of performance measurement at STC. The recorded data of Isc were converted to 1000 W/m^2 and 25°C by using temperature coefficient of Isc. PV11 was cleaned to quantifying soiling accumulation of PV12 by using the ratio of I_{soiled} to I_{clean} at any observation dates. From the results, it is found that (1) maximum soiling accumulation is 8.8%, (2) soiling accumulation increased 6.6% for a period of 42 days with no rain, and (3) rate of increasing of soiling accumulation on clean glass was higher than rate of increasing on the soiled glass of PV modules. It means that dust deposition rapidly increases after cleaning PV modules. It may be explained by the adhesive force, due to gravity and electrostatic, of the first layer or the earlier layers of dust deposition is more than other layers of dust deposition, especially in dry season. Finally, the power loss due to soiling accumulation of PV modules of a PV system, were preliminarily also observed and compared to the reduction of Isc of the module. Difference of this work is to use the precision measurement from the standard laboratory for evaluation soiling accumulation of field observation. This research mostly benefits for PV power plants in Thailand because there clearly demonstrate the effects of dust accumulation on electrical performance of PV modules. Moreover, the maintenance costs regarding the cleaning of PV modules can be done with optimum solution for operation of PV power plants.

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