Techno-financial assessment of dust impact on 8 MW PV power plant in Thailand

Maruphong Konyu[1], Chatchai Sirisamphanwong[2] and Nipon Ketjoy[1,*]

[1]School of Renewable Energy and Smart Grid Technology (SGtech), Naresuan University, Phisanulok 65000, Thailand

[2]Department of Physics, Faculty of Science, Naresuan University, Phitsanulok 65000, Thailand

***Corresponding author's email**: niponk@nu.ac.th

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Abstract

This paper is an e analysis of how dust decreases the electrical power output from photovoltaic (PV) modules by altering the solar spectrum and thereby obstructing the absorbance of solar irradiance by the PV modules. The research were done for 300W polycrystalline silicon modules installed for a 8 MW PV power plant in Phichit province. The output of a clean module surface with that of a dusty surface was compared by calculating the solar irradiance in the measured wavelength range of 350-1,050 nm of spectral irradiance. The income or revenue difference of the PV power plant, with clean and dusty PV moduel surface were analyzed. The findings revealed that accumulated dust affects solar irradiance transmission by 4.02%, causing a decrease of irradiance in the wavelength range of 380-760 nm (visible light). In the high irradiance effect of the dust will be reduced. At a solar irradiance higher than 600 W/m^2, the effect of dust will be in wavelengths 350-550 nm. However, in the case of solar irradiance lower than 600 W/m^2, the effect of dust will be in wavelengths 350-800 nm. Dust accumulation causes power output degradation of a PV module by reducing the solar irradiance and the transmittance. Power output degradation is linear with the dust accumulated density. The dust accumulation reduces PV power output, after 30 days by 2.8% and after 60 days by 6.2%. When the PV modules of the power plant are not clean for a long time, the monthly revenue from the sale of electricity is greatly reduced to a maximum of 359,000 baht. Therefore, dust accumulation should be removed or at least minimized so that PV modules operate at optimal efficiency.

Keywords:

Dust, Solar spectrum, Photovoltaic.

1. Introduction

The rapid economic growth and the increasing world population, have led to higher energy requirements. Traditional energy sources, particularly fossil fuels, are negatively impacting the global the environment.

In Thailand, energy consumption during the last few years has continued to rapidly increase and this e trend will continue because of the changing lifestyle that is driven mainly by globalization. Fossil fuels are non-renewable energy resource and the negative environmental impacts of their use, particularly climate change, has driven most countries to develop renewable energy sources. Renewable energy sources are not only infinite resources, the use of these resources have also minimal environmental impact. Solar energy is one type of renewable energy source that is now increasingly being used.

Thailand has a high solar energy potential of around 1,800 kWh/m^2.year [1]. The country's Alternative Energy Development Plan 2015-2036 (AEDP 2015) [2], which was approved by the national energy policy council (NEPC), aims for a 30% share of renewable energy sources in the total energy consumption by 2036. This means that the target capacity for solar energy installation will be 6,000 MWp [3].

The present installed capacity of the Photovoltaic (PV) systems in Thailand is about 3,000 MW. PV modules directly convert solar energy into electricity and can be used widely various types of electrical applications. PV module output power is rated with the following standard test conditions (STC); specific irradiance 1000 W/m^2, a module temperature of 25 degree Celsius, and air mass at 1.5.

However, the conditions in the field cannot be controlled, so the performance (output power) of PV modules varies according to the local conditions, such as environmental variables, solar irradiance, current, and previous day environmental conditions, such as; temperature, relative humidity, wind speed, shading, and soiling. The three most important environmental parameters affecting the electrical power output of PV modules are solar irradiance, temperature and dust accumulation.

The effect of solar irradiance has been studied in many countries such as in Thailand solar spectra with average photon energy of three seasons which the solar irradiation is calculated from each wavelength measured in the range 350-1050 nm [4].

Dust accumulation obstructs solar irradiance and affecting different ranges of the solar spectrum. This effect has been studied in many countries such as in Santiago, the capital of Chile. Exposure of photovoltaic systems to the elements for over two years (2014–2015) showed that t critical cleaning was required every 45 days in real conditions Between the first and second year of the operation, the system degraded; by 2.77% for thin film PV, 1.29% for polycrystalline PV, and 1.74% for monocrystalline PV [5].

In India, dust samples from six different geographic locations encompassing the country's diverse climatic conditions were examined. The dust in Mumbai affected the module technology the worst, with degradation for amorphous silicon by 17.7%, followed by cadmium telluride by 15.7%, crystalline silicon by 15.4%, and CIGS by 14.5% [6]. The accumulated dust obstructed the irradiance affecting the various range of the solar spectrum.

The energy loss due to dust has been calculated using the well-known software PVsyst, which showed a reduction of 1.6 percent. The Photovoltaic system design book [7] was also used, and it showed an energy loss of 2 percent due to dust.

However, the environment and climate in Thailand is different from European countries where the formulas were developed. Dust accumulation in Thailand is greater than in Europe, which causes, in Thailand, a higher reduction in electricity production from the PV modules.

When electricity production decreases, the revenue for the power plant drops, increasing the payback period, which may affect the decision to invest in other projects. In this research, we studied the effect of accumulated dust on the 8 MW PV power plant which is located in Phichit, by collecting dust data and using the PVSyst program to analyze the electrical energy produced.

2. Method

The energy in solar irradiation comes in the form of electromagnetic waves of a wide spectrum. Longer wavelengths have less energy (for instance infrared) than shorter ones such as visible light or UV. The solar irradiation that passes through the atmosphere, gasses, dust, and aerosols absorb the incident photons. The major factor reducing the power from solar irradiation is the absorption and scattering of light due to air molecules and dust. Dust is described as an airborne particulate matter, ranging in diameter from 10 to 50 microns, generated by activities such as cutting, crushing, detonation, grinding, and handling of organic and inorganic matter.

The spectral irradiance studies were done at the 8 MW PV power plant which is located in Phichit province, Thailand. The field research used the US EPA (United States Environmental Protection Agency) Method 5 [8] for detecting the accumulated dust. The spectral irradiance distributions of solar spectra were recorded for the wavelength range of 350-1,050 nm by using a Spectroradiometer (EKO MS-720). The PV analyzer (EKO MP-11) was used in measuring the characteristic curve of the PV modules, both for the clean and dusty ones. The PVSyst program was used to estimate the effect of dust on PV power output and calculate the finance income from the selling of electricity, compare between cleaning and dirty one. The cleaning process required hiring cleaners, which cost 30,000 baht per 1 MW.

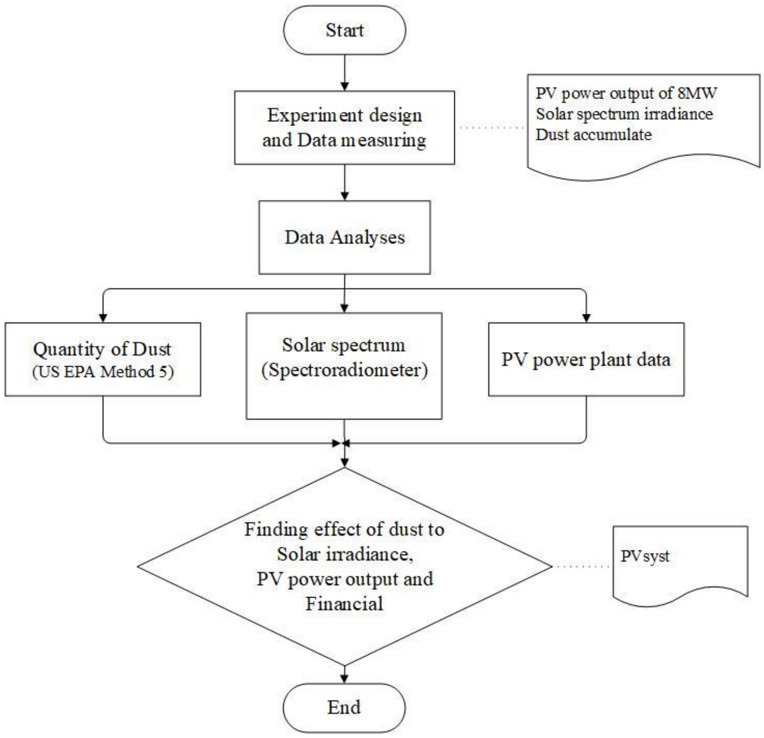

Fig. 1 Detailed methodology used in this study.

3. Results and discussion

3.1 Quantity of dust

The average quantities of dust, which accumulated on the PV modules in 7 days, 14 days, 30 days and 60 days were 60 $mg/m^2 \cdot d$, 130 $mg/m^2 \cdot d$, 260 $mg/m^2 \cdot d$ and 420 $mg/m^2 \cdot d$ respectively as shown in figure 2. This dust accumulation caused a maximum solar irradiance decrease of 11.10% (at the 60-day mark).

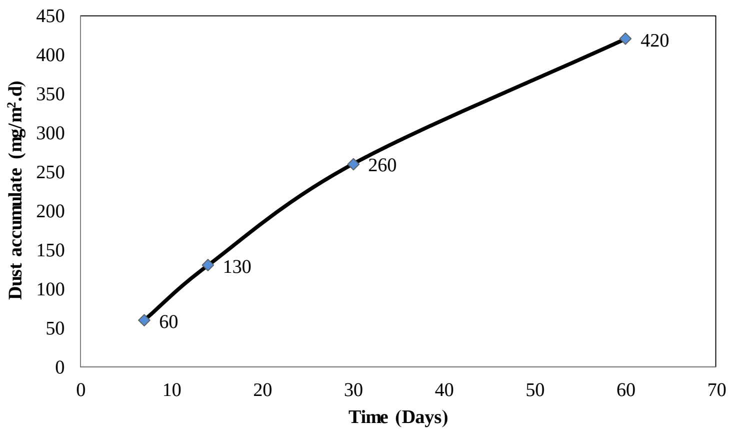

Fig. 2 Show the accumulate dust in 60 days.

3.2 Solar spectrum

The dust accumulated on the PV module are particles that can increase absorption, refraction, reflection or obstructs the irradiance by affecting the different range of the solar spectrum. In case of solar irradiance lower than 600 w/m^2 the dust can affect in the 5 range of wavelength. The spectral irradiance is decreased in wavelength of 350 – 900 nm, with the minimum of 1.30 % in 800 – 900 nm range and the maximum of 3.63 % in 400 – 500 nm as range shown in Fig. 3.

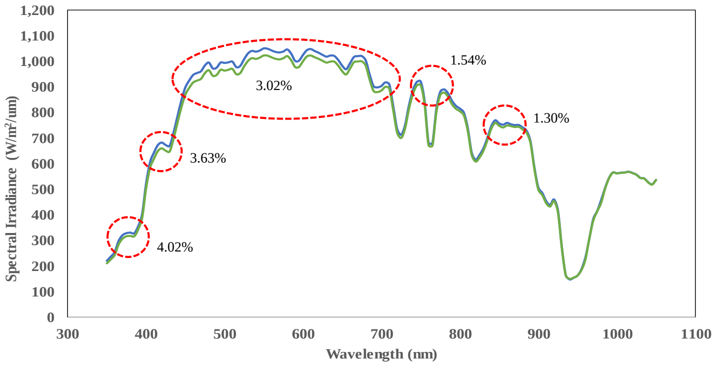

Fig. 3 Show the solar irradiance decreased by dust at solar irradiance lower 600 W/m^2.

The accumulated dust affects light transmission and decreases irradiance in the solar irradiance of over 600 W/m^2. The spectral irradiance is decreased for wavelength of 380 – 760 nm (visible light), with the minimum of 2.22 % in the 600 – 700 nm range and the maximum of 2.79 % in 400 - 500 nm range as shown in Fig. 4.

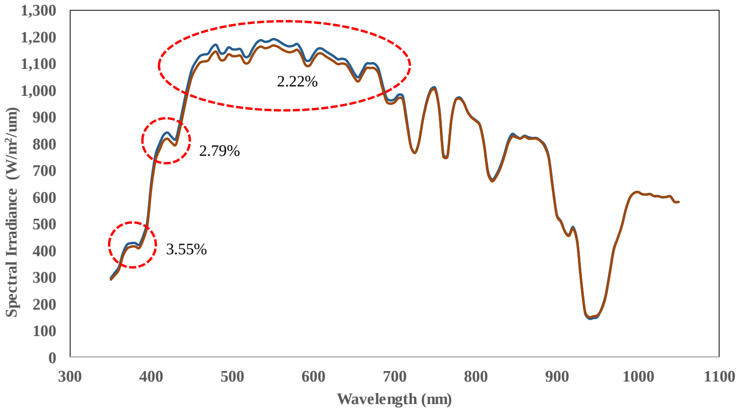

Fig. 4 Show the solar irradiance decreased by dust at solar irradiance over 600 W/m^2.

From the data, it can be seen that the accumulated dust affects the spectrum in the range of 350-700 nm. It is affecting the electricity production of p-Si PV, which is used in this power plant, in the spectrum response range between 305 and 1,200 nm as shown in fig. 5

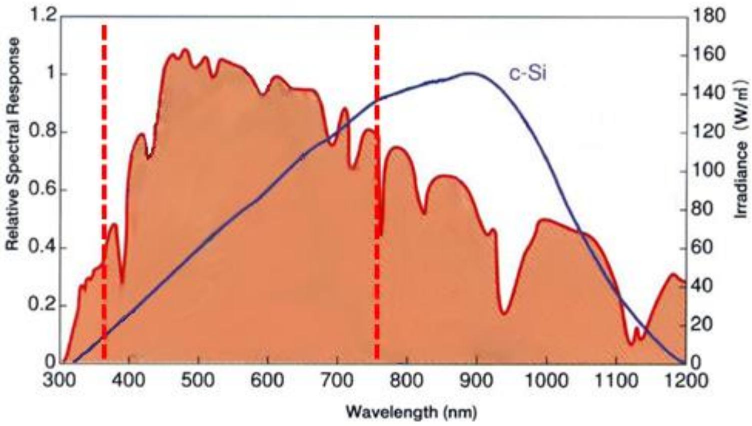

Fig. 5 The spectrum response of p-Si PV and the effect of dust to spectrum.

3.3 PV power

The maximum power (Pmax) of the clean PV module is reduced about 8.9 watts or 2.8% after 30 days of without cleaning and by about 15.7 watts or 6.2 % after 60 days of without cleaning. The maximum power is obtained from P = I*V (Current multiply Voltage), which is the area under the graph. When the dust accumulates on the PV, the transmission of solar irradiance decreases and that affects the solar spectrum in various wavelengths, causing the current of PV to decrease, thus affecting the power output as shown in fig. 6.

In the same context, Kaldellis et al. [9] studied PV modules affected by airborne dust. His study showed that the deposition of dust causes completely different effects on photovoltaic performances, which was reduced by 2.3% to 7.5%.

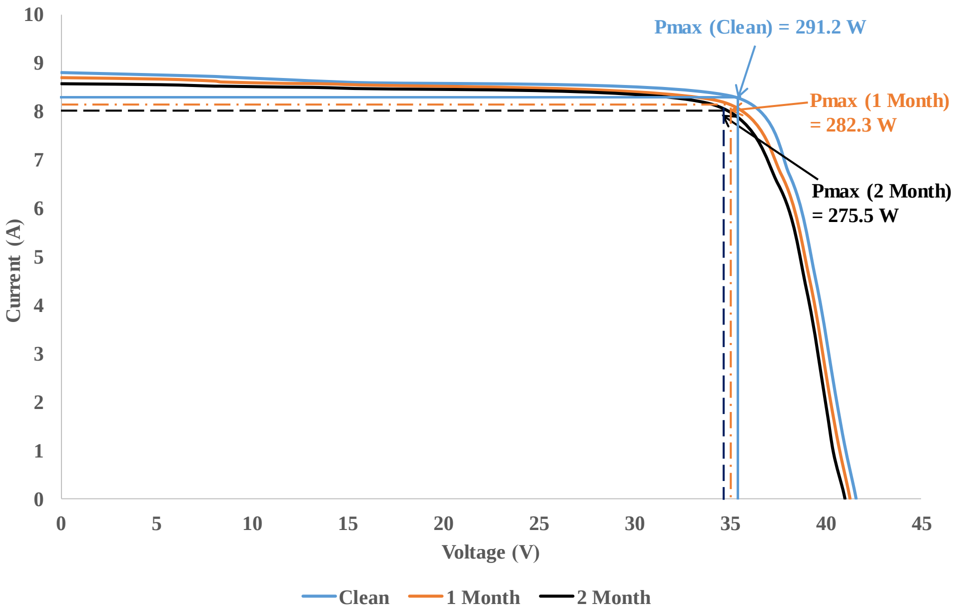

Fig. 6 Effects of dust on poly crystalline silicon PV module: reduced I-V Curve.

The level of airborne dust at the power plant under this study was compared to the data from the Air quality measuring station of the Pollution Control Department, in Phichit province [10]. The power output degradation for a whole year from accumulated dust on an 8 MW PV power plant in Phichit, was analyzed from both data sources using the PVsyst program [11]. Throughout the year dust accumulation alters due to the seasons, which results in a differentiated PV power output.

Using the same types of PV modules, experiments were conducted to simulate the effect of dust on the 8MW PV power plant in Pichit province. The simulations use the PVsyst program and the results is shown on Fig. 7 and 8. The amount of dust in each month varies. l. The amount of dust in the air also depends on the air pressure condition. During winter, when high-pressure conditions cover Thailand, there is low temperature and low wind flow There is more dust in the air during other seasons.

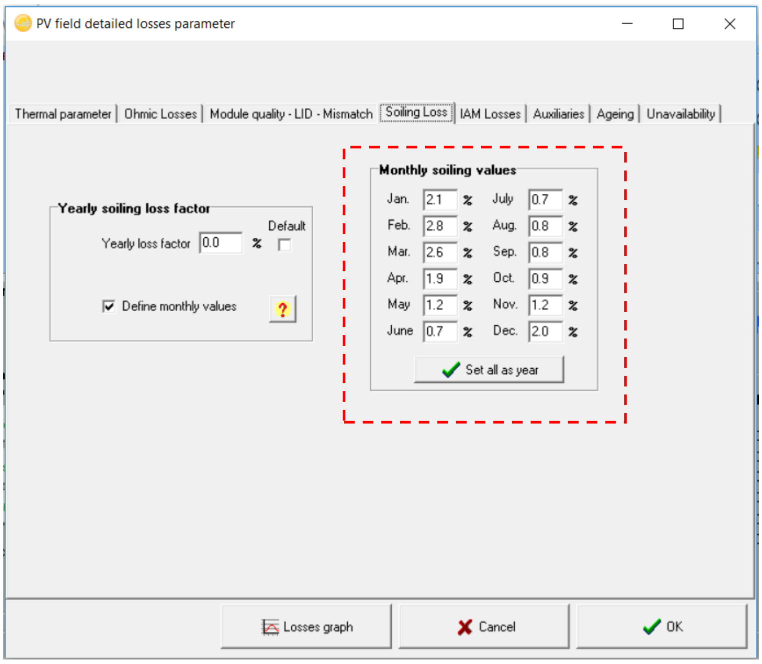

Fig. 7 The Soling effect of 30 days on polycrystalline silicon PVs in PVSyst program.

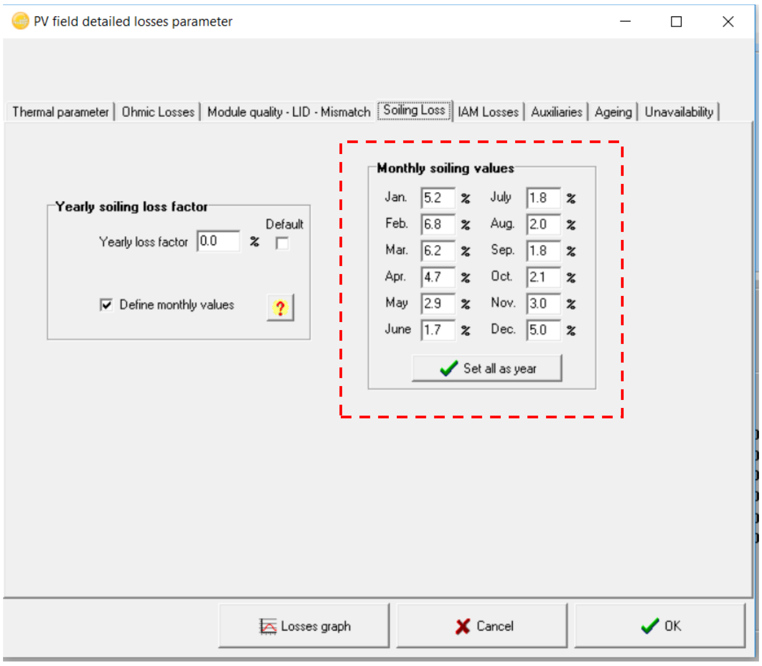

Fig. 8 The Soling effect of 60 days on polycrystalline silicon PVs in PVSyst program.

Fig. 9 shows the lost energy output of polycrystalline silicon PVs. During the rainy season, from June to September, power loss was negligible due to the rain washing the dust off the PV surfaces. The annual cycle of dust accumulation begins around October when the rainy season ends. Output loss due to dust starts in earnest in November, increasing to a maximum loss in February, and then gradually declined due to occasional rain showers that lead back into the rainy season. The annual minimum power loss in July in the middle of the rainy season.

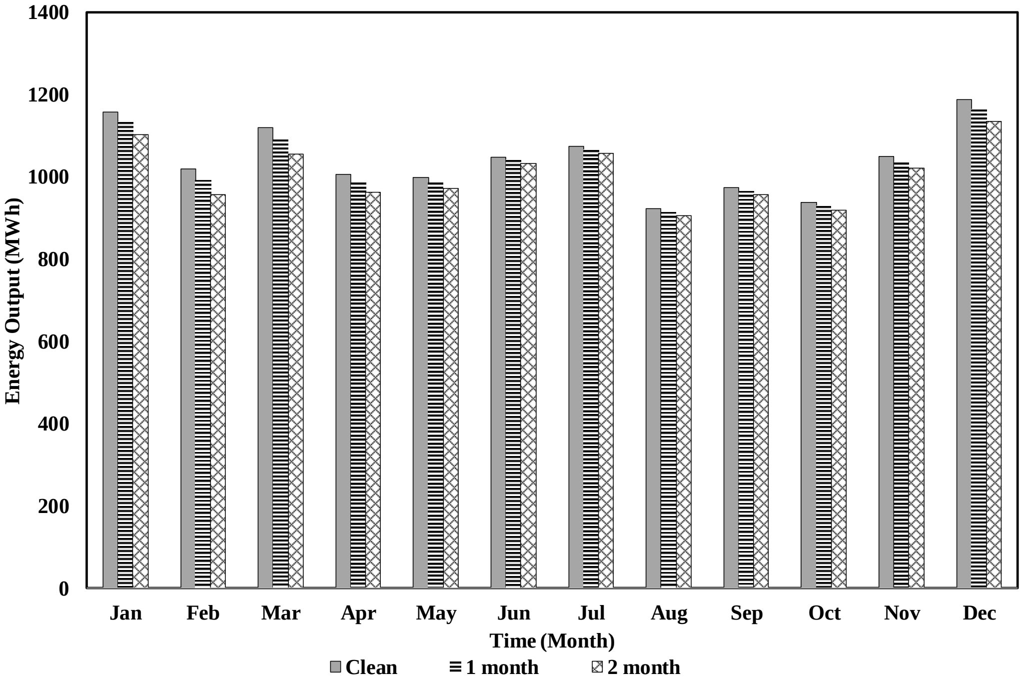

Fig. 9 Lost energy output of 8 MW PV power plant.

3.4 Financial

The financial aspects of this study are explained in the following discussions:

- The feed-in tariff of the power plant is set at 5.66 baht.
- Cost of hiring cleaners is about f 240,000 baht per time.
- The Energy production is calculated from the PVSyst program

The cost of one-time cleaning of the PV power plant is more than the income from the sale of electricity from one-month operation, which, at the maximum is about 162,000 baht. After two months operation, the income from the sale of electricity rises to a maximum of 359,000 baht, well above the cost one-time cleaning (see Table 1).

Table 1 Energy production, benefit, and cost of cleaning.

	Electricity Generation (MW)			Benefit (Baht)				
	Clean	1 Month	2 Month	Clean	1 Month		2 Month	
					Benefit	Different	Benefit	Different
January	1158	1133	1103	6,554,280	6,414,728	139,552	6,245,273	309,007
February	1020	991	957	5,773,200	5,611,550	161,650	5,415,262	357,938
March	1119	1090	1055	6,333,540	6,170,979	162,561	5,973,584	359,956
April	1006	987	963	5,693,960	5,584,351	109,609	5,451,255	242,705
May	999	987	973	5,654,340	5,586,724	67,616	5,504,618	149,722
June	1048	1041	1032	5,931,680	5,890,158	41,522	5,839,739	91,941
July	1074	1066	1057	6,078,840	6,034,515	44,325	5,980,692	98,148
August	922	914	905	5,218,520	5,175,902	42,618	5,124,152	94,368
September	973	966	957	5,507,180	5,465,417	41,763	5,414,705	92,475
October	937	929	919	5,303,420	5,257,015	46,405	5,200,666	102,754
November	1049	1036	1021	5,937,340	5,864,608	72,732	5,776,290	161,050
December	1188	1164	1134	6,724,080	6,586,797	137,283	6,420,096	303,984

Table 1 shows that when dust accumulated on the PV modules for two months, some months the revenue more than expenditure to cleaning. During some months the revenue less than expenditure to cleaning, such as during May to November. However, during the rainy season, the rains help clean off the dust from the PV modules, causing the impact of dust to decrease. Therefore, the researchers suggest that cleaning of PV modules every month during December to April forget the highest income.

5. Conclusions

In this research, we measured the solar irradiation in each wavelength using a Spectroradiometer on clean and dusty PV module surfaces under the same environment conditions. The average amount of dust accumulated per day on the PV modules for periods of 7, 14, 30 and 60 days were 60 $mg/m^2.d$, 130 $mg/m^2.d$, 260 $mg/m^2.d$ and 420 $mg/m^2.d$, respectively. The quantity of dust decreased the electrical energy output from the PV module by 2.80% after one month and 6.20% after two months. The accumulation of dust over one month affects the light transmission and decreases irradiance in the wavelength range of 380 - 760 nm (visible light). In high irradiance, the effect of dust will be reduced. At a solar irradiance higher than 600 w/m^2, the effect of dust will be in the wavelength range of 350-550 nm. However, in the case of solar irradiance lower than 600 w/m^2, the effect of dust will be in the wavelength range of 350-800 nm. At high solar irradiance, the effect of accumulated dust will be reduced, due to it having lower wavelengths with more energy and photon flux. From these results, the dust effect decreases solar irradiance and the power output of PV modules, and the power output degradation is linear due to the density of the accumulated dust. However, the degree of power output reduction can be affected by type of PV module and the type of dust. The accumulation of dust on any given PV module surface depends on the type of dust, surrounding environment, weather, module properties, and its installation design. If the PV modules of the power plant are not clean for a long time,t the revenue from the sale of electricity can be greatly reduced. Monthly revenue is reduced to point that it becomes lower than the cost of cleaning. The study shows that the power plant should be cleaned every month. There will be cost savings during the rainy season, when there is lesser and the rains help in cleaning the PV modules. Dust accumulated on PV modules affects the solar irradiance transmission in all ranges and reduces power output regardless of the PV module type. Therefore, dust accumulation should be eliminated or at least minimized so that PV modules operate at optimal efficiency.

6. Acknowledgments

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