Effects of Dust Accumulation on the Efficiency of Solar PV Panels in Malaysia

by

Mohamad Nur Hidayat Mat

Dissertation submitted in partial fulfilment of
the requirement for the
Bachelor of Engineering (Hons)
(Mechanical)

MAY 2014

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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Approved by,

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(Assoc. Prof. Ir. Dr. Shaharin Anwar Sulaiman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMAD NUR HIDAYAT MAT

ABSTRACT

Solar energy is a renewable source of energy and can be found almost anywhere. In Malaysia, individuals or organizations can earn income by selling solar power generated at their premises to Distribution Licensees like Tenaga National Berhad under the Feed-in Tariff (FiT) scheme which is fully governed by the Sustainable Energy Development Authority (SEDA), a Malaysia Government body that manages the sustainable energy development in Malaysia. Solar PV panel on the other hand is used to trap solar energy and convert it to electrical energy. Solar energy is one of the main promising clean energy sources in future as it is environmental friendly and provides cost effective solutions to energy problems. However, dust accumulation on solar panel can reduce the efficiency of solar PV panel system and therefore it would affect the amount of power generated and also the cash flow of the producer of solar power. Many studies conducted in different countries showed that accumulated dust on the collector can reduce the performance of solar panels by up to 65% in duration of 6 months in Egypt. However there has been no study conducted in Malaysia to determine the reduction in performance of solar PV panel due to accumulated dust on the collector panel within the local environment condition. The main objective of this project was to study the nature of dust accumulation on solar PV in Malaysia over period of time and its consequence performance. The study was conducted experimentally on the roof of a building in Universiti Teknologi PETRONAS, Perak, Malaysia. To determine the performance of solar PV panel system, glass dummy panels and PV panels were used for comparison in term of sun radiation and power output generated from PV panel. The nature of dust settlement on the PV panel was studied in order to obtain time-based trend which benefit users in term of maintenance of cleaning the solar panel so that it could sustain optimum power delivery. From the result, it was found that the mass of dust accumulated on the solar PV panel developed very fast at a rate of 0.0217 g/hr, Furthermore, it was estimated that the projected drop in power output in a year in Malaysia was about 6 %. A study on interval of cleaning was done by using optimum profit gain of selling solar energy with maintenance of cleaning time. It was found that solar PV panels in Malaysia should be best cleaned against dust at an interval of 2 months for industrial owners and every month for residential owners in order to earn maximum profit gain of selling solar energy.

ACKNOWLEDGEMENT

First and above all, the author would like to express his highest gratitude to his supervisor, Assoc. Prof. Ir. Dr. Shaharin Anwar Sulaiman, for all the motivation, knowledge and valuable advices that he has given. The guidance and supervision from him have granted his many opportunities to explore, learn and experience throughout the project.

The author is also very grateful to Dr. Fiseha Guangul and Mr. M. Fahmi Ramely who provided the author constructive advices and valuable assistances in accomplishing the project. This project would not be a success without the technical helps from the laboratory assistants. They are Mr. Khairul Azman, Mr. Hasri Luqman and Mr. Mior Razali. Their kindness and hospitality provided the author a comfortable and conducive working environment.

Finally, the author would like to extend his appreciation to Universiti Teknologi PETRONAS(UTP) especially for giving financial support for Semester 1 and 2 and providing the facilities and learning opportunities. The author also appreciate the financial support from the sponsorship program, Jabatan Perkhidmatan Awam for the author's undergraduate study at UTP and also to his family and friends who constantly supported him throughout the project.

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CHAPTER 1

INTRODUCTION

1.1 Background

Generation of electricity around the world is mainly produced by using non- renewable energy sources, especially fossil fuels. However, these resources will be largely used up at some time in the future (Sayigh, 2009). Such situation forces us to look for renewable energy. Solar energy is one of the main promising clean energy sources in the future as it has a lot of advantages. Among the advantages of solar energy is it is long lasting, can be used almost anywhere and it provides cost effective solutions to energy problems. According to the estimation of International Energy Agency, global energy consumption will be increased by 53% in 2030, with 70% of the growth in demand coming from developing countries (Oh et al., 2010). In Malaysia, individuals or organizations can earn income by selling solar energy to Distribution Licensees (DL) like Tenaga National Berhad under the Feed-in Tariff (FiT) scheme that is fully governed by Sustainable Energy Development Authority (SEDA) in Malaysia.

Malaysia is one of the most developing countries among ASEAN countries next to Singapore, with GDP of US$15,400 per capita, and steady GDP growth of 4.6% in 2009 (IMF, 2010). Malaysian economy grew at 5% in 2005 and overall energy demand is expected to increase at an average rate of 6% per annum (Saidur et al., 2009). In parallel with Malaysia's rapid economic development, final energy usage consumption grew at rate of 5.6% from 2000 to 2005. The crucial challenge facing the power consumption in future forces many country ventures into the use of renewable energy. In Malaysia, green technology application is seen as one of the sensible solutions which are being adopted by many countries around the world to address the issues of energy and environment simultaneously. It was reported that among all the renewable energy sources in Malaysia, solar energy is the most prospective one in Malaysia (Islam et al., 2009).

Most of the solar power generated in Malaysia is used at domestic level whereas large scale commercial use is not yet significant (Islam, 2009). In addition, The Government of Malaysia has promoted a variety of energy related policies. In the Eight Malaysia Plan, The Government fixed a target of 5% renewable energy of the total energy mix in 2001-2005 but achieved only around 1%. Again in 2006, the Government declared the Ninth Malaysian Plan having the same target of 5% renewable energy of the total energy consumption. But it is quiet impossible to achieve this target as the implementation of the policies has not been pragmatic (Oh et al., 2010).

On the other hand, reduction of performance of solar PV system due to dust accumulation tends to discourage its use as an alternative energy. The degradation of solar PV panel system is normally due to the accumulation of dust on solar PV panel that would reduce the practical efficiency of the system. Moreover, deposition of dust, bird droppings and water-stains of salt can significantly degrade the efficiency of solar PV panel installations (Mani & Pillai, 2010). Typical a solar PV system would only last for about 25 years due to cracks in the glass, shattered glass and corroded inter-cell tracks (Green, 2012). Appropriate installation of solar panel system such as orientation, exposure, sun-tracers is very important to maximize the absorption of solar radiation which can ensure sustained yield of electricity continuously.

Current research into characterizing deposition of tiny particle and their impact on PV system performance is a complex phenomenon and is influenced by diverse site-specific environmental and weather conditions in the atmosphere from various sources such as fine lifted up by wind, pedestrian, vehicular movement and pollution. Dust settlement mainly relies on the dust properties which are chemical properties, size, shape and weight as well as on the environmental conditions which are site-specific factors, environmental features and weather conditions. The surface finish of solar panel, tilt angle, humidity and wind speed also affect the dust accumulation on the surface (Kaldellis & Kapsali, 2011).

1.2 Problem Statement

Solar energy for generation of electrical power through PV panels is advantageous as it is free from environmental pollutions, sustainable and requires low maintenance. However, dust accumulation due to natural causes on solar PV panel can reduce the performance of solar PV system. Studies conducted in different countries showed that accumulated dust on PV panels can reduce performance of the solar power generation system. However there has been no study conducted on the trend of dust accumulation and the frequency of cleaning maintenance of solar panels against dust in Malaysia. To determine the reduction of performance of solar PV panel due to natural causes of dust settlement on solar PV panel, a study of dust accumulation in Malaysia would be required.

1.3 Objectives

The objectives of this project were:

1. To study the trend of dust accumulation over different time period and its cleaning maintenance of solar PV system at a location in Malaysia.
2. To investigate the effect of dust accumulation on the performance of solar PV panels in Malaysia.

This project was expected to provide operators of solar PV panel systems with beneficial guidelines of cleaning interval for PV panels so that the system could continuously deliver power at its best and results in high return to investment.

1.4 Scope of Study

The study was conducted experimentally at Universiti Teknologi PETRONAS, Malaysia. The duration of experiment was three months only due to the limited time available for Final Year Project (FYP). The experiment was located in an outdoor area in order to expose it to real dust particles. Furthermore, the effect of parameters such air humidity, air velocity and inclination PV panel angle were not be considered in the scope of this study as they were already studied by researchers in the past. No modelling or numerical simulation were conducted in this study as it focused on the natural behaviour of dust accumulation on the solar PV panel surface.

CHAPTER 2

LITERATURE REVIEW AND THEORIES

This chapter covers the literature review pertaining to researchers on the effect of dust accumulation on efficiency of the solar PV panel system. The history of solar PV system is presented in Section 2.1 giving an overview of solar PV system and its performance. Section 2.2 presents the basic operating principle of solar energy system and Section 2.3 gives details on efficiency of present solar PV panel system. Tropical Asian dust is discussed in Section 2.4 giving an overview on the type and characteristic of dust in the area of conducting this project. Section 2.5 explains on the effects of dust on solar PV system performance regarding to power reduction generated from solar PV system due to its dust accumulation. Discussions on issues pertaining dust accumulation of solar PV panels is presented in Section 2.6.

2.1 History of Photovoltaic Systems

The physical phenomenon responsible for converting light to electricity which caused by photovoltaic effect was first observed in 1839 by a French physicist, Edmund Becquerel. Becquerel noted a voltage appeared when one of two identical electrodes in a weak conducting solution was illuminated. The PV effect was first studied in solids, such as selenium, in the 1870s. In the 1880s, selenium photovoltaic cells were built that exhibited 1%-2% efficiency in converting light to electricity. Selenium converts light in the visible part of the sun's spectrum for this reason it was quickly adopted by the then-emerging field of photography for photometric devices (Bell, 1994).

Even today, light-sensitive cells on cameras for adjusting shutter speed to match illumination are made of selenium. However, selenium cells have never become practical as energy converters because their cost is too high relative to the tiny amount of power they produce at 1% efficiency (Suzanne, 1996). Meanwhile, work on the physics of PV phenomena has expanded. A major step forward in solar-cell technology came in the 1940s and early 1950s when a method which called the Czochralski method was developed for producing highly pure crystalline silicon (Robert, 1998).

In 1954, a work at Bell Telephone Laboratories resulted in a silicon photovoltaic cell with a 4% efficiency. Bell Labs soon bettered this to a 6% and then 11% efficiency, heralding an entirely new era of power-producing cells. A few schemes were tried in the 1950s to use silicon PV cells commercially. Most were for cells in regions geographically isolated from electric utility lines (Gilbert,1995). But an unexpected boom in PV technology came from a different quarter. In 1958, the U.S. Vanguard space satellite used a small (less than one-watt) array of cells to power its radio. The cells worked so well that space scientists soon realized the PV could be an effective power source for many space missions. Technology development of the solar cell has been a part of the space program ever since (Basic Photovoltaic Principle and Methods, 1982).

2.2 Basic Principle of Photovoltaic Systems

Solar panels harness the energy of the sunlight and convert it into usable electricity. Photons are the basic fundamental unit of any form of light energy. The photons that are emitted by the sun are captured by the solar panels. The generation of electricity in the solar panels is possible because of a principle called as the photovoltaic effect. The photovoltaic effect is the creation of an electrical voltage or electric current flowing in a closed loop in a solar panel (Joseph, 2005). The electrons that are generated when the solar panels are exposed to a stream of photons are transferred between the different bands of energy inside the atom to which they are bound. This transfer of electrons makes them accumulate in order to cause a build-up of voltage between the two electrodes Photovoltaic systems behave in an extraordinary and useful way. They react to light by transforming part of it into electricity (George, 1997). Moreover this conversion is novel and unique, since photovoltaic system has no moving parts to wear of and it contain no fluid or gases that can leak out as do some solar-thermal systems. Moreover, the system produces no pollution while producing electricity and consumes no fuel to operate as the system is a green energy (Solar Energy Home, 1996.).

2.3 Solar Cell Efficiency

Solar efficiency refers to the amount of light that can be converted into usable electricity. Solar PV panel efficiency refers to the amount of light that the entire module converts to electricity (Bernice, 2008). The efficiency of a solar PV panel is lower due to the spacing between cells and the glass covering th panel reflects away some of the sunlight. Consequently, paying attention to solar panel efficiency is important because that will indicate how much electricity the solar energy system will actually generate (Sun Power, 2014).

2.4 Asian Dust in Tropical Country

What is dust? Dust is little robust particles, taken as those particles below 75 μm in diameter, which settle out under their own weight however which may stay suspended for some time (International Standardization Organizatio,1994). In Eastern Asia, mineral dust originated in springtime in the Gobi Desert which are in Southern Mongolia and Northern China and gives rise to the phenomenon called Asian dust. The aerosol is one type of Asian dust which is carried out by prevailing winds, and pass over China, Korea, and Japan (Perry, 2007). The Asian dust storm aside from African dust is one of the two major global dust transport events and exports huge amount of dusts originating from the Takla Makan and Gobi deserts across China and into Korea and Japan (Kellogg and Griffin, 2006). The dust storms usually occur in the spring and affect global and regional environment, such as visibility reduction and change of radiative forcing (Kim et al., 2009). Several studies have reported that these dust can be associated with biological particles including bacteria, fungi and viruses (Hua et al., 2007). This far-reaching transport comes about the health effects of allergens carried in the dust and the possible transport of pathogens (Kellogg & Griffin, 2006).

Aerosols dust particles is the most common dust particle in Asia. They are soil particles suspended in the atmosphere in regions with easily erodible dry soils, little vegetation and strong winds. Furthermore, inhalation of dust aerosol is hazardous to human health. The small size of dust would give greater chance of deposited in the gas exchange of the lung and consequently give adverse affect to human health (Brunekreef & Holgate, 2002)

2.5 Effect of Dust on PV Cell Performance

Dust consists of particles in the atmosphere that come from various sources such as soil, dust lifted by weather, volcanic eruptions, and pollution. According to Kosa in 2002, dust contains small amounts of plant pollen, human, animal hairs, textile fibers, paper fibers, minerals from outdoor soil and human skin cells in homes or in other human environments area. There have been different studies conducted in different to investigate the effect of dust on solar cells. In United State, it was reported that a degradation in collector performance was about 4.7%, which was due to dust deposition (Hottel & Woertz, 1942). Moreover, it was reported that 40% degradation in duration of six month period in Saudi Arabia (Nimmo & Said, 1979), Meanwhile 32% reduction was reported in duration of eight month time again in Saudi Arabia (Mani and Pillai, 2010), Moreover in Kuwait, 17% - 65% reduction on the performance of solar panel was reported due to tilt angle of solar collector (Sayigh, 1985). In another study done in Egypt 33.5%–65.8% reductions in performance was reported in duration of one to six months exposure (Hassan et al., 2005). In tropical country, 11% reduction was reported in Thailand for a period of one month (Mastekbayeva & Kumar, 2000). Overall, all researchers had focused on the time duration over the degradation of solar panel rather than the quantification of dust accumulation on the solar panel.

The effect of dust’s size also gives significant impact on the performance of solar PV panel system. Mani et al., (2010) was done the experiment on the effect of dust’s size on the performance of solar PV panel system. The experiment was entirely simulated with artificial dusts which were limestone, cement and carbon particulates under constant halogen lamps. It was reported that fine carbon particulates of 5 mm in diameter was found to have the most deteriorating effect on the PV efficiency. The study also found the impact of finer particles to have a greater impact than coarser particles on PV performance for the same dust type. In addition, the same experiment also has been conducted by the different author, Sulaiman et al. (2011). Two different size of artificial dusts were used which were mud and talcum. From the result, it showed that talcum powder had lower power output generated as compared with the mud dust**.** In general, both researchers showed the same result for the impact of dust size on the performance of PV panel system.

There was an investigation done by Kazem et al. (2013) on the effect of PV panel for indoor condition. The PV module performance was tested under the deposition of different pollutants which were red soil, ash, sand, calcium carbonate, and silica. From the experiment, it showed that the drop of PV module's voltage and output power were affected by the mass of accumulated and the type of pollutant. In another study done by El-Shobokshy and Hussein (1993) on the physical properties and deposition density of dust on the solar PV panels the artificial dust which included limestone, cement and carbon particulates. It was reported that the cement particles at 73 g/m^2 would result in the most significant drop in the PV short-circuit voltage by 80%.

Natural dust is one of the most abundant in the atmosphere. There was an experiment done by Kazem et al., (2013) in Omani desert area on the effect of natural dust on the performance of solar PV panel. From the result, it showed that, the PV modules generated the highest power when it was clean and cool. While, reduction in the output power occurs when the panel was dry and clean and suffers a larger reduction in output power. On the other hand, different author Rahman et al., (2012) also has conducted the same experiment on natural dust in Bangladesh. From obtained result, it showed that the power output for clean panel was greater than the power output for dusty panel.

2.6 Dust Accumulation on Solar PV Panel Surface

There are many factors that influenced the dust settlement on the solar PV panel which are dust's type, size, shape and weight of dust. The tilt angle of solar PV panel also influences the dust accumulation on the solar PV surface. Hottel and Woertz (1942) were amongst the pioneers investigating the impact of dust on solar systems. They had carried out the experiment on the performance of solar collectors in duration of 3 months in 1940. From obtained result, it was found that 1% degradation in the performance of solar PV collector was due to dust accumulating on a glass plate inclined at an angle of 30^o from horizontal in an industrial area of the United States of America. In another study done by Garg (1974) on the influence of dirt on solar transmittance by comparing glass plate and plastic films at Roorkee, India. The study concluded that the horizontal glass received more dirt than a vertical one. Moreover another study done by

Sayigh et al. (1985) on the effect of dust accumulation on tilted glass plates located in Kuwait and it was found that a reduction in plate-transmittance by an amount ranging from 64% to 17% for tilt angles ranging from 0° to 60°, respectively after 38 days of exposure. In addition, a reduction of 30% in useful energy gain was observed by the horizontal collector after three days of dust accumulation. Again similar study done by Nahar and Gupta (1990) on the performance of solar PV panel based on inclination angle showed that dust settlement decreases with increase in tilt from the horizontal. The reduction in transmittance for glass was found to be 19.17%, 13.81% and 5.67% for tilt angles 08, 458 and 908.

Haeberlin and Graf (1998) studied accumulation of pollution by iron dust and other components at the edges of framed solar cell modules in Burgdorf. The dust accumulation reduces the performance of solar panel output power up to 8-10%. When the material of dust was analysed, the conclusion was due to the dust in Burgdorf environment composed from iron oxide, silicon and some of organic materials. Mazumder et al., (2002) studied the dust deposition mechanisms on a solar module, the conclusions was due to the reduction in solar modules performance depends on the particle size, shape, distribution, deposition mechanisms and orientation of dust deposits on the module. In a different study conducted by Timothy et al., (2007) on three main categories which were dust adhesion, surface electric fields and dust transport. It was concluded that mechanical adhesion resulted from the barbed shapes of the dust grains, and dust adhered to space suits both mechanically and electrostatically.

Another study done by Mohamed and Hasan (2012) on the effect of dust accumulation on performance of PV solar module in Sahara environment concluded that, the accumulations of dirt objects on solar module have a significant impact on output power and overall system performance. In another study done by Dietz et al., (1963) on the effect of sun irradiation reaching the PV panel showed that 5% reduction in solar radiation due to dust accumulation on the horizontal tilt angle of PV panel. Michalsky et al., (1988) had compared the performance of two pair of solar PV collector in Albany, New York. One was clean daily whereas the other was left alone for a testing period of two month. It was found that panel that left for 2 month period give less than 1% reduction in power output.

CHAPTER 3

METHODOLOGY

This chapter discusses on the methodology used to study the effects of dust accumulation on the efficiency of solar PV panels in Malaysia. The installation of equipment and the approach of conducting all the experiments are discussed in this chapter. Section 3.1 gives an overview of the methodology used in conducting the experiement and brief introduction for every section in this chapter. To ensure the project follows proper steps, section 3.2 presents the work flow of the project by giving step by step of executing the experiments and facilitate the flow of the project starting by familiarization of equipments until reporting the data.

To make sure the project finish within the time period of FYP Semester 1 and 2, Gantt Charts for Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2) are presented in Section 3.3. In addition, Section 3.4 stress on the key importance in Section 3.3. Project key milestones provide guideline throughout the project in order to meet the objective of this project successfully. Start with familiarization of the system by completing the finding of dust patterns on a different time scale. On the other hand, section 3.5 presents on the location of experiment. The experiment was conducted in outdoor area in order to expose solar collector to real dust particle and it was located at academic complex, Universiti Teknologi PETRONAS (UTP), Perak, Malaysia.

Section 3.6 shows the installation framework diagram that was located on rooftop block 17 in a building of academic complex UTP. Apart from that, Section 3.7 describes the experimental block diagram of the solar PV panel system. In general 3 pairs of panels were used to study the effect of dust accumulation on its consequence of power drop. Section 3.8 provides the details on the optimum tile angle of solar PV panel in the area of conducting the experiment based on study done by other researchers. Overall, readers are able to understand the work flow of the project in details and gives guidelines on how the experiments were conducted.

3.1 Overview of Method

Figure 3.1 shows the overview of project planning starts with the literature review, familiarization of the system, installation of the system, record the data, analyze the data and conclude the findings. A literature review was used to study to the background of the research project. Familiarization of the PV panel system is important before designing the real test rig. The designing of test rig was depending on the output parameters to be measured which were sunlight irradiation and power output. The data on power output and irradiation were collected from the system in order to analyze and interpret the result. Last but not certainly least, the result was recorded in the report for submission.

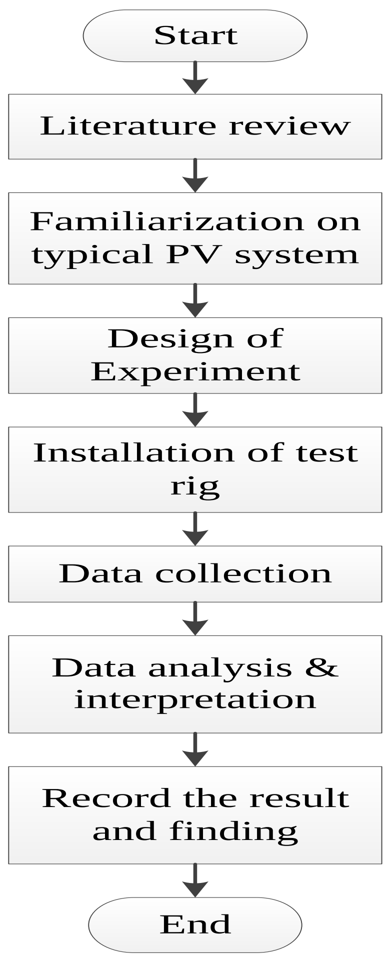


Figure 3.1 Overview flow chart

3.2 Gantt Chart and Key Milestones

Figure 3.2 and 3.3 show the project's Gantt Chart for Semester 1 and 2. These Gantt Charts were used as a reference to complete the project within the time period. The contents in the Gantt Chart start with preliminary research work until record the result and analyses the dust pattern. The key milestone was embended together with the Gannt Chart. Key milestones are a useful tool as it provides a guideline to meet the objective of this project successfully. Start with familiarization of the system on February 2014 until concluding the finding in the report on July 2014. The first process is important in order to precede the experiment for the project. On March 2014, the data can be recorded after doing the experimental planning. The data have been interpreted and analyzed on June 2014. Submission of the report was done on July 2014.

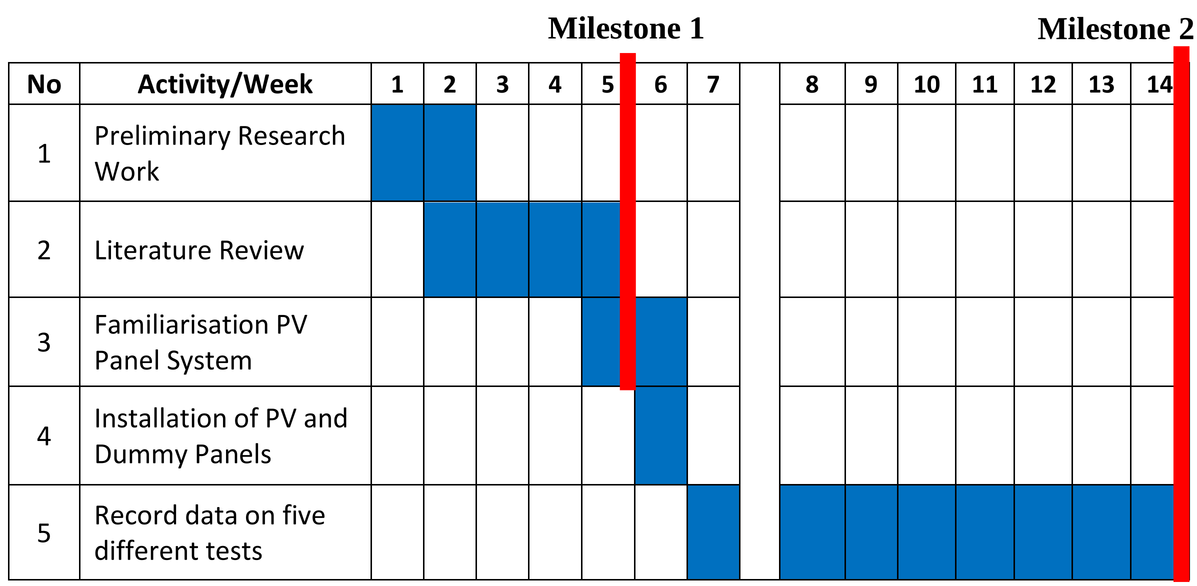


Figure 3.2 Gantt Chart for Semester 1

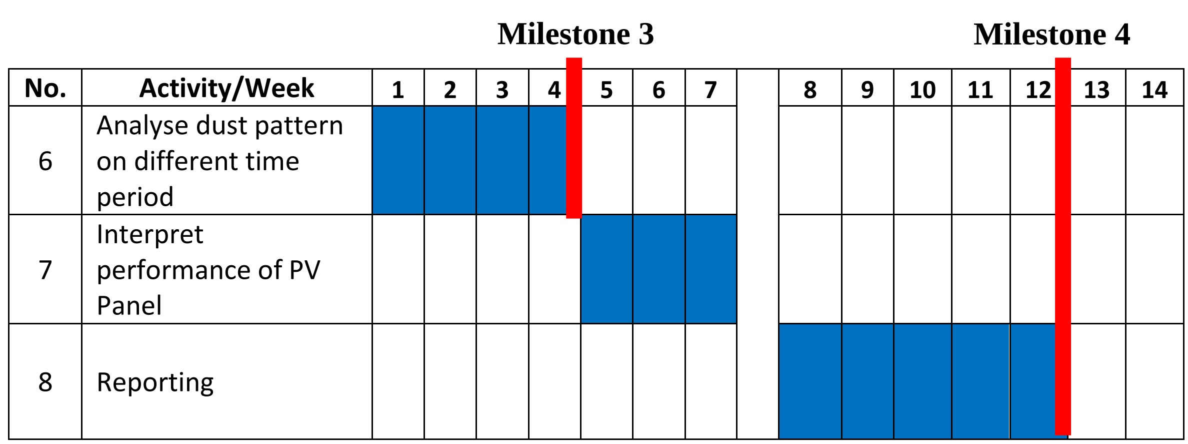


Figure 3.3 Gantt Chart for Semester 2

3.3 Location of Experiment

Figure 3.4 shows the location of installation of solar PV panel system. The installation of the system was located at on the rooftop of block 17 of the department of Mechanical Engineering Department Block 17, Universiti Teknologi PETRONAS in Perak, Malaysia. This site was located less than 200 km to the North of Kuala Lumpur, with a ground elevation of about 60 m from the sea level. The height of the building of about 40 m from the ground level. The location of installation was surrounded by the forest on the side of the building and it was away from the external effect of dust to the panel. Therefore, the natural effect of dust alone can be conducted carefully within the boundary of the building.

In this study, a mono-crystalline photovoltaic module was used. The PV modules were connected to the Midi Data Logger while the glass panels having LDR probes underneath the surface were connected to the Arduino Microcontroller (Solarimeter). In this research, outdoor experiment was conducted to investigate the performance of PV panel in term of power output and sunlight irradiation in Malaysia. These two sets of panels were used to measure the performance of clean panel relative the dirt panel for hourly test, daily test, weekly test and monthly test. In order to determine the impact of dust accumulated on the surface, the clean panel was always being cleaned while the dirt panel was cleaned on different time interval depends on the required test for this project (hourly, daily, weekly and monthly test).

On the other hand, the solarimeter and voltmeter were used to measure directly from the panel for two output parameters which were sun irradiation and power output. These output parameters need an additional parameter which was mass of dust. Since the mass of each panel was 10 kg, thus an extra piece of glass of size 10 cm by 10 cm area and thickness of 6 mm was used during conducting the experiment as the measuring scale only capability to measure mass of objects up to 2 kg. The sensitive measuring scale was used to measure the mass of dust on every experiment. The 2 pieces of glass were used to measure mass of dust accumulated on clean and dirt glass panels. To determine the mass of dust accumulation, the difference in mass between the clean and dusty panel indicated the mass of dust accumulated on the panel surface.

Figure 3.4 Location of installation at academic complex Block 17 (Google map, 2014)

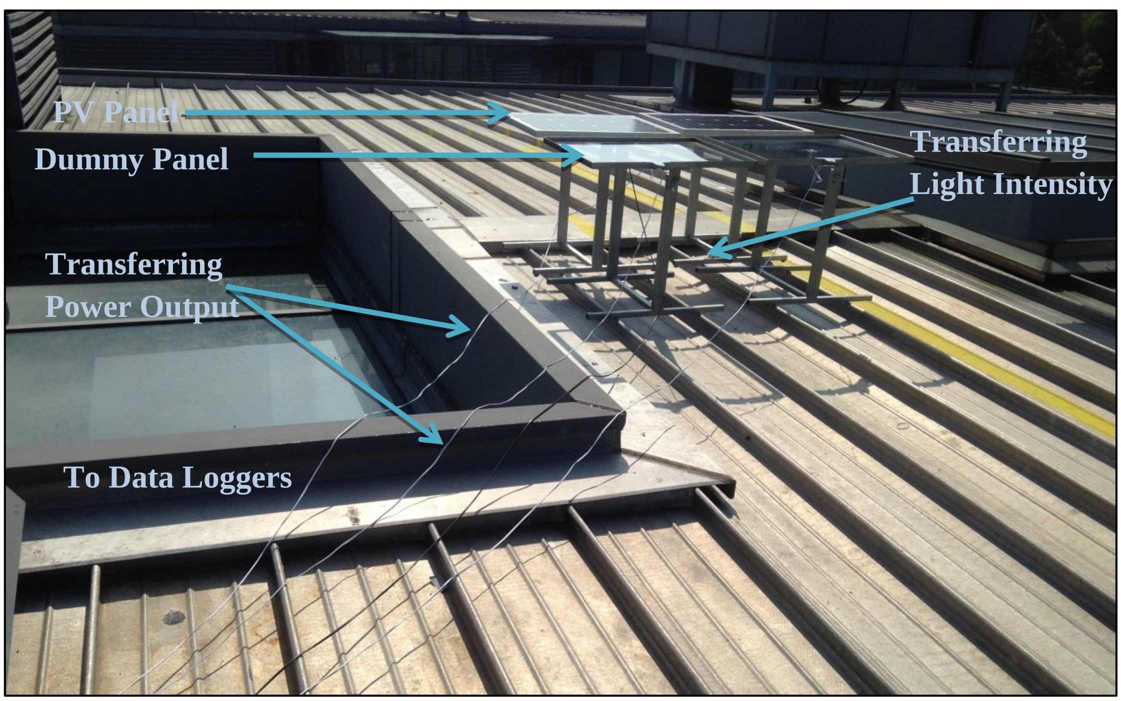
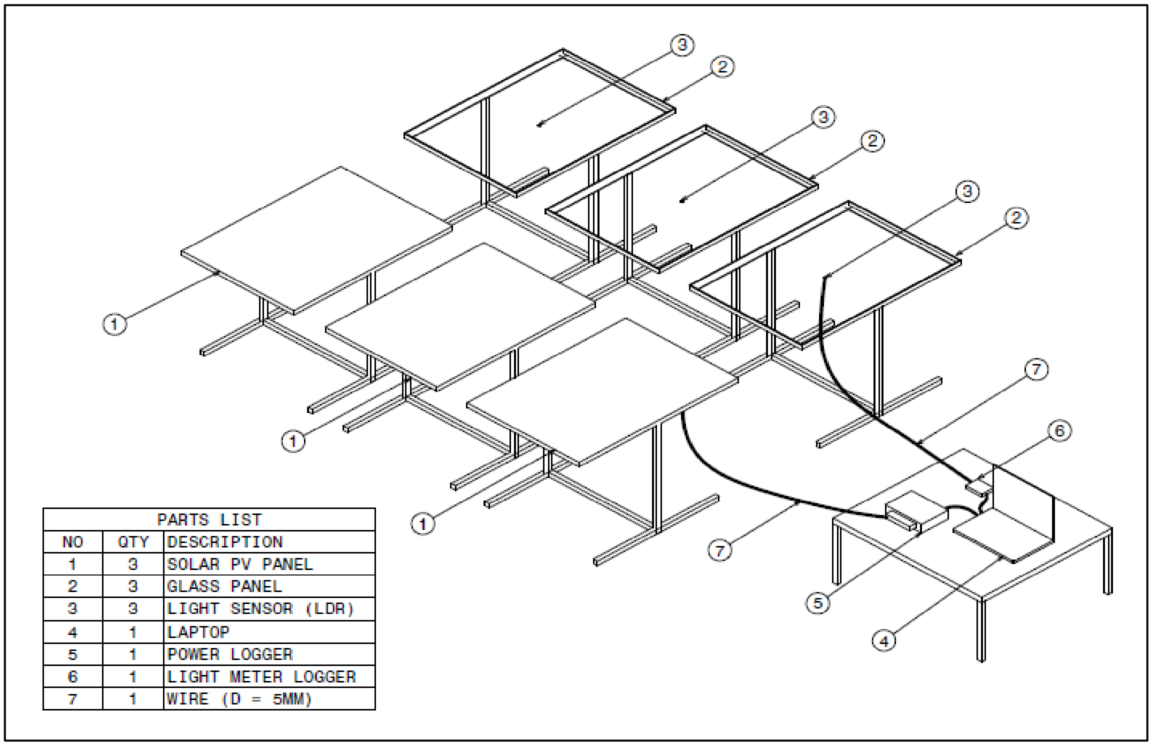


Figure 3.5 Equipment set-up of solar PV panel system

3.4 Framework of Installation



PARTS LIST		
NO	QTY	DESCRIPTION
1	3	SOLAR PV PANEL
2	3	GLASS PANEL
3	3	LIGHT SENSOR (LDR)
4	1	LAPTOP
5	1	POWER LOGGER
6	1	LIGHT METER LOGGER
7	1	WIRE (D = 5MM)

Figure 3.6 Isometric view of solar PV panels system

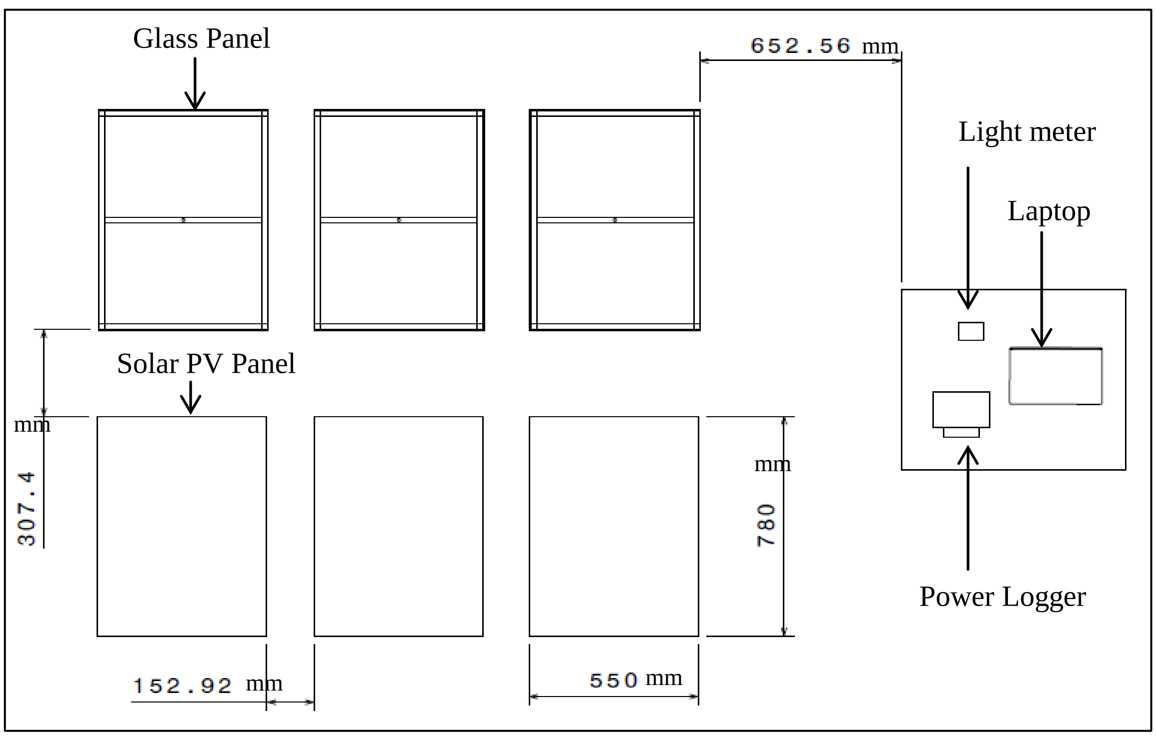


Figure 3.7 Top view of solar PV panels system with dimension

3.5 Custome Made of Photometer

Figure 3.8 shows the custom made of solarimeter. The system was made by a combination and integration of Microcontroller named as Arduino Microcontroller, Breadboard and Light Emitting Diode (LED). The Light Emitting Diode (LED) works as a sensor that capture the sun irradiation underneath the glass panel and sent the input signal to microcontroller for processing. Arduino microcontroller is the heart of the system. It functions as a brain to translate the input from raw data in this case the sun irradiation to digital value which is the value of sun irradiation. The connection between microcontroller and LED was performed by using Breadboard. The Breadboard is important to make a complete circuit. In order to make the program follow the instruction, programming the microcontroller has to be done first prior running the system. The programming of the system was done by considering the two inputs which were coming from clean and dusty panel and continuously calibrating the value in order to make the result as accurate as possible. The sample of coding can be seen in Appendix D.

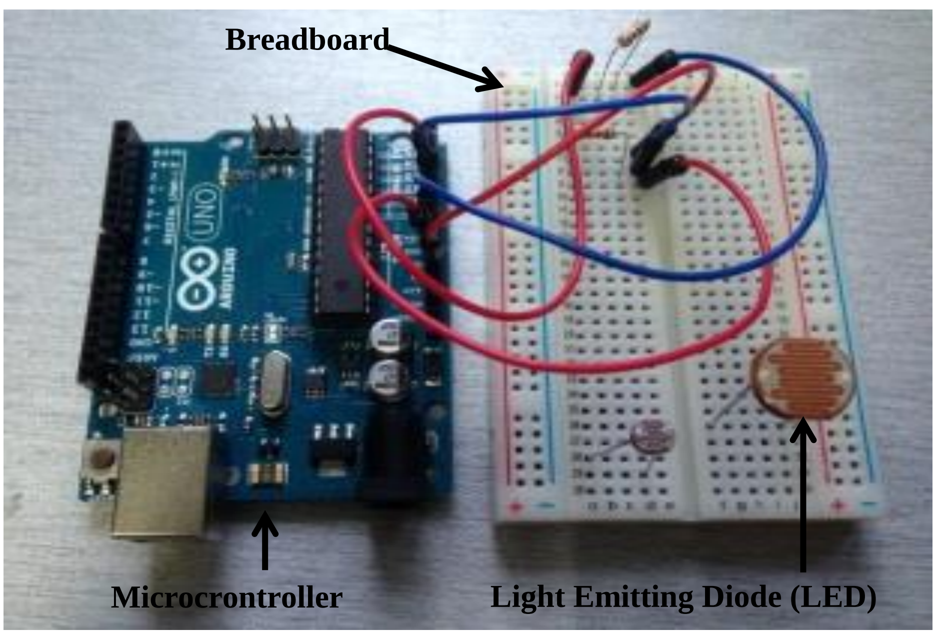


Figure 3.8 Custome made of Solarimeter

3.6 Block Diagram of Solar PV Panels System

Figure 3.9 shows the block diagram of solar PV panels and glass dummy panels to the data acquisition and recording PC. The diagram shows how the experiments were conducted. In general, three pairs of panels were used during conducting the experiment. The first panel is a solar PV panel while the second panel is a glass dummy panel. Both of these panels were used to measure the performance of the solar PV panel system in term of solar irradiation and power output generated from the PV panels. In order to measure the performance of solar PV panels in quantifying the measuring scale, dust accumulation on solar PV collector was taken into consideration in this study. The mass of dust was measured by taking the dirty glass panel and compared with clean panel. The difference between them indicated the mass of dust accumulation. The clean and dusty panel was compared during conducting all the experiments. The clean solar PV panel was cleaned at all times while the dirt panel was left to accumulate with dust based on the different test. For example, the panel for weekly test would left accumulate for every week, then at the end of the week the data would be recorded accordingly and being compared with clean panel.

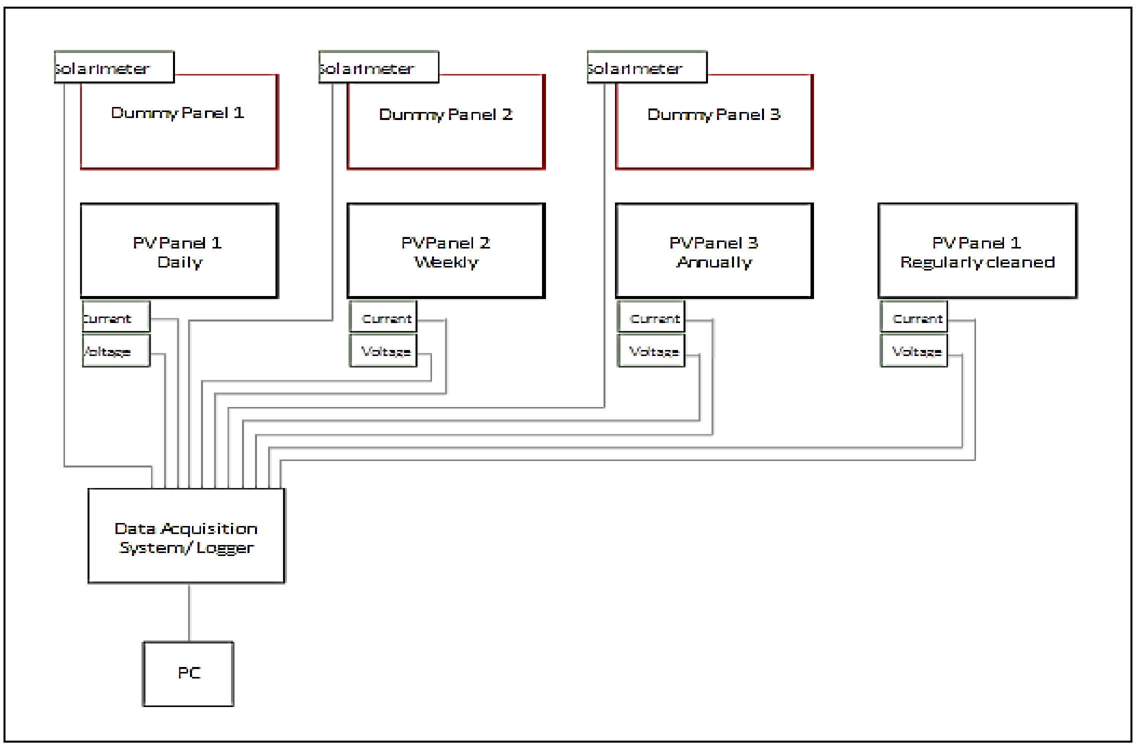


Figure 3.9 Block diagram of solar PV system

3.7 Optimum Tile Angle of Solar Panel in Malaysia

Figure 3.10 shows monthly optimum tilt angle of solar PV panel for the five sites in Malaysia. In order to get maximum exposure of sunlight irradiation to the system, the solar PV panels need to be inclined at correct inclination angle. Based on the study conducted by Khatib et al., (2012) on the monthly optimum tilt angle of solar PV panel for five sites in Malaysia which were in Kuala Lumpur, Johor Bahru, Ipoh, Kuching and Alor Setar, it was reported that the optimum tilt angle at month of April until August was 0° inclination angle for all sites in Malaysia. Since the project was done from March 2014 to June 2014 based on the project key milestones in Universiti Teknologi PETRONAS, Perak Malaysia, therefore the inclination angle during conducting the experiment would be at 0° inclination angle. Moreover, since the optimum inclination angle in Ipoh is 0° within April to August, thus the panel can be placed at any direction as the horizontal plane would have no effect on the direction of the panel to be located.

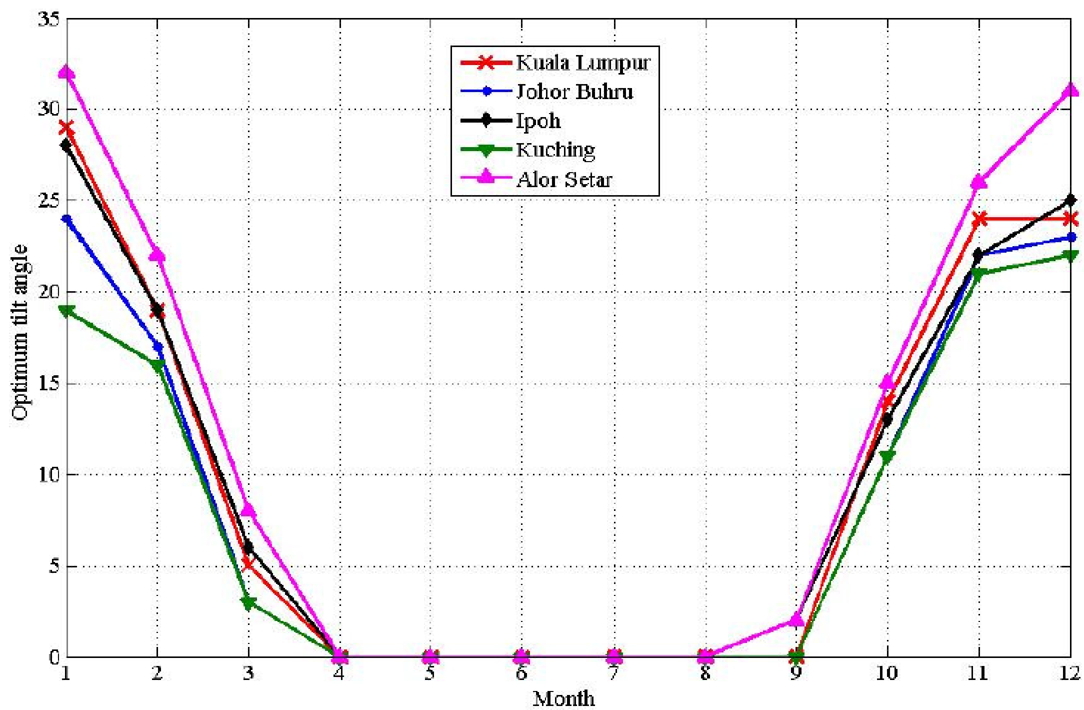


Figure 3.10 Monthly optimum tilt angle for five sites in Malaysia (Khatib et al., 2012).

CHAPTER 4

RESULTS AND DISCUSSIONS

This chapter presents the results and discussions on the performance of the solar PV panel system in Malaysia based on a different time scale. This chapter shows the result in sequences started from hourly in section 4.1 until continuously 3 month test in section 4.5. In order to make sure the results were consistent, three measurements were made on every test that was conducted. The result for the first test was presented in each section while the rest was presented in the appendices. In every section of section 4.1 to 4.5, three data were presented which were variation of power output and irradiation with time, variation of performance drop with time and distribution of mass of dust with time. From the result, further extraction and summarization of all the tests (hourly, daily, etc.) were presented in a single graph in section 4.6 in order to analyse and make comparison for all tests. Proposed cleaning maintenance of solar PV panels for industrial and residential was presented in section 4.7. This section explains about the method used to find the best interval of cleaning time based on the optimum profit gain by both sectors.

4.1 Hourly Test

4.1.1 Variation of Power Output and Irradiation with Time on Hourly Test

Figure 4.1 shows the variation of power output and irradiation with respect to time for hourly test 1. The hourly test was conducted three times. The first result of hourly test was presented in this section while the rest was presented in the appendices. The first hourly test was conducted on 3 May 2014, continue to hourly test 2 and 3 on 4 and 5 of May 2014 respectively. It was observed that during conducting all the tests, the weather was good as there was no rain and haze for the particular of days. The hourly tests were conducted from 10 am to 6 pm. There were two pairs of panels which were glass dummy panels and solar PV panels. Glass dummy panels were used to measure irradiation underneath the glass panels for clean and dusty panels while the solar PV panels were used to measure the power output for clean and dusty panels. In general, first pair of panels were left unclean for 1 hour and the second pair of panels were always clean at all times. The reading was measured continuously throughout the day. In Figure 4.1, the green line indicates the clean power output while the purple line indicates the dusty power output. From obtained result, it showed that there was almost no significant different between clean and dusty power output. The two lines were overlapped to each other. This was due to frequency of cleaning time on every hour. The dust accumulated on the dusty panels was cleaned at every hour. There was also no significant deviation happened during the peak hour test from 12 pm to 3 pm. On the other hand, the irradiation from glass dummy panels as indicates by a blue line as clean panel while red as dusty panel also showed no significant difference between the two lines. The two lines were overlapped to each other. This was also due to shorter frequency of cleaning time on every hour. Furthermore, the variation of power output and irradiation showed the same pattern especially during peak hour from 12 pm to 3 pm and during un peak hours from 4 pm to 5 pm. The variation of the two parameters which were power output and irradiation showed the same pattern was because the panels was receiving the same amount of light intensity of solar irradiation. In addition, all the two pairs of panels were located side by side so that all the panels received equal amount of solar irradiation. The arrangement of panels can be seen in section 3.4, framework installation of solar PV panels system.

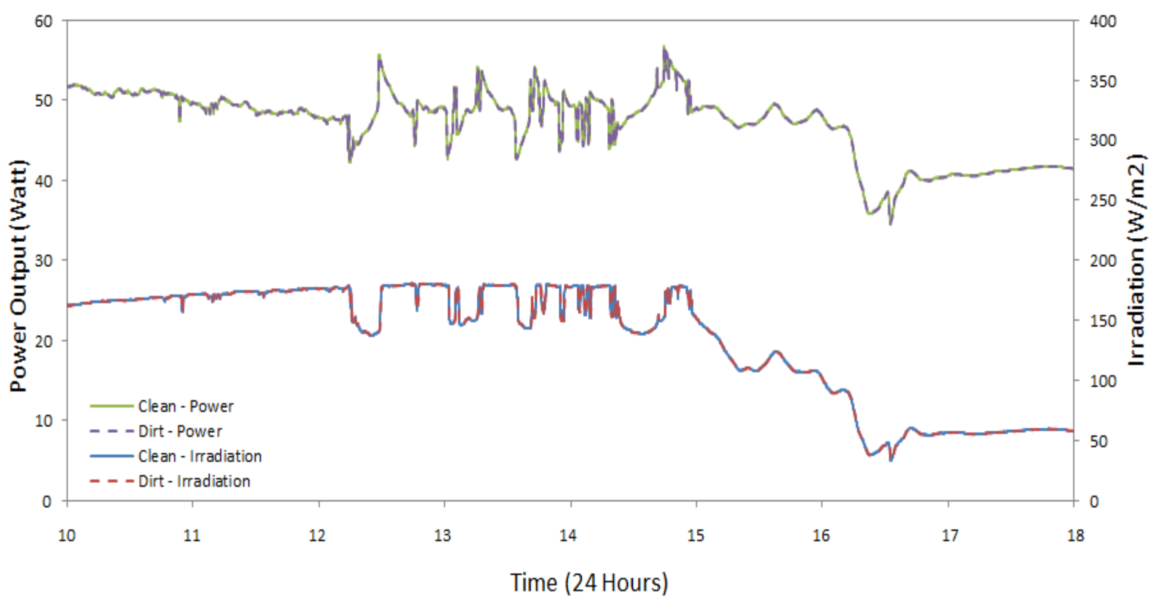


Figure 4.1 Variation of power output and irradiation with time for hourly test 1

4.1.2 Variation of Performance Drop with Time on Hourly Test

Figure 4.2 shows the variation of performance drop with time for hourly test 1. The result, as in Figure 4.2 was derived from the result in Figure 4.1, the variation of power output and irradiation with time. The difference between clean and dusty panels for power output and irradiation was presented in Figure 4.2. The blue line indicates the performance drop of power output while the red line indicates the performance drop of irradiation. From obtained result, it showed that the peak performance drop of power output and irradiation was happening around 5 pm. This result can be correlated in Figure 4.1 where at 5 pm, the intensity of solar irradiation at this period was lower. On the other hand, the average performance drop of power output was about 0.04 %, while the average performance drop of irradiation was about 0.01 %. Theoretically the performance drop of power output and irradiation suppose to be the same, however due to the efficiency of solar PV panels used was low, that's why there was a gap between the two lines.

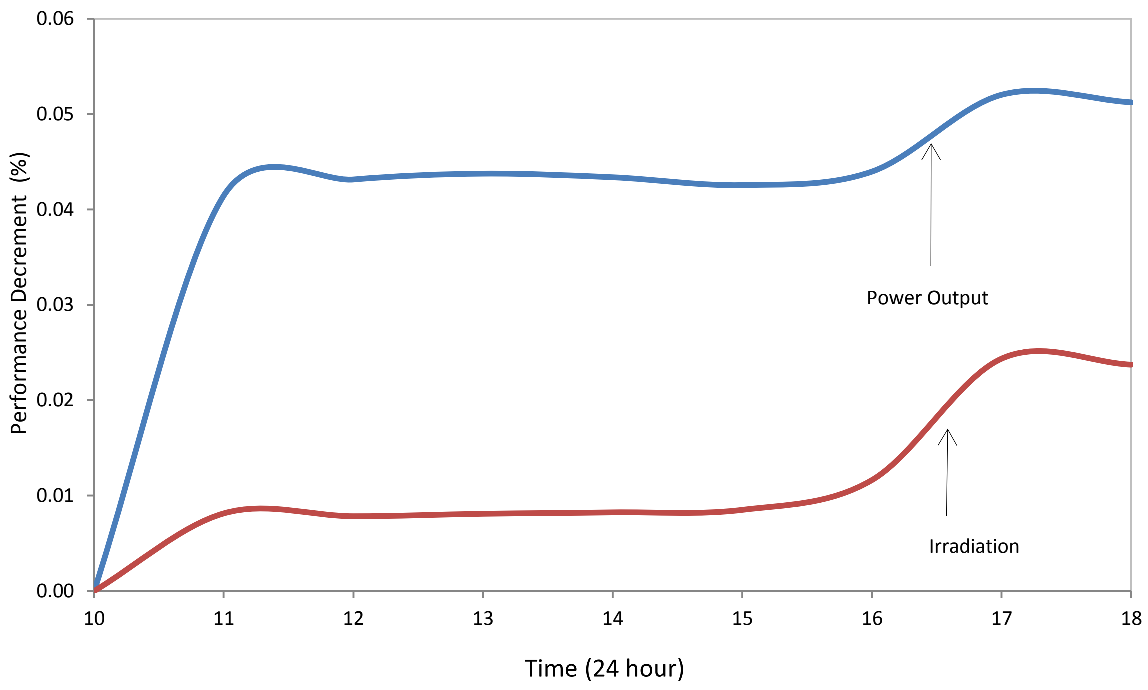


Figure 4.2 Variation of performance drop with time on hourly test 1

4.1.3 Distribution Mass of Dust with Time on Hourly Test

Figure 4.3 shows the distribution, mass of dust with time. The mass of dust was collected from the dusty panel on every hour start from 10 am to 6 pm. The sensitive measuring scale was used to measure the mass of dust accumulates on the solar PV collector. The difference between dusters to clean panels indicates the mass of dust accumulates on the solar PV collector. The blue bar indicates the mass of dust on every hour and the red line indicates the theoretical cumulative mass of dust. From obtained result, it showed that the average mass of dust accumulated on hourly test was about 0.02 g per 0.01 m^2 area of the panel. The high mass of dust was occurring at 5 pm. It was observed that around 5 pm, the wind speed was faster and this contributed to the dust accumulated on the panels. Theoretically, the mass of dust accumulates on the solar PV collector from 10 am to 6 pm was about 0.17 g per 0.01 m^2 area of panels. The mass of dust accumulated on the clean panel increased gradually throughout the day. The mass of dust showed a constant reading occurred at 1 pm to 4 pm. The constant value of dust's mass was about 0.02 g per 0.01 m^2 area of the panel.

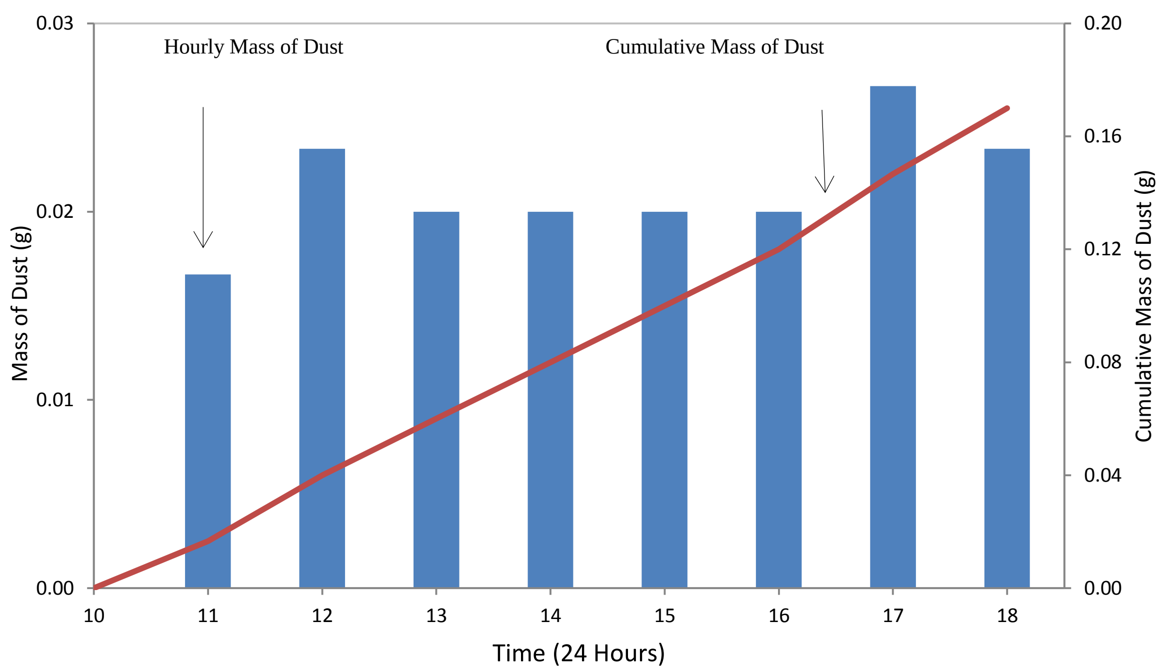


Figure 4.3 Distribution of dust with time on hourly test 1

4.1.4 Summary of Hourly Tests on Irradiation

Figure 4.4 shows the summary of all hourly tests on the irradiation. The blue bar indicates the irradiation from the clean panel while the red bar indicates the irradiation from dusty pane. The glass dummy panels were used to provide the data in term on sunlight irradiation underneath the glass panels. Hourly test 1, 2 and 3 were conducted in 3, 4 and 5 of May 2014 respectively, and the test was conducted from 10 am until 6 pm. It was observed that during conducting the hourly tests, the weather was good for every hourly test as there was no rain and haze at outside. From the result, it was found the hourly test two had the highest irradiation value compared to hourly test 3 and 1. On the other hand, the difference in value of irradiation for clean and dusty panel for hourly test 1, 2 and 3 were the same for all the tests which was 0.02 W/m^2 and the decrement for all the test was 0.015 %. In summary, the average difference in irradiation value for clean and dusty panel for all the hourly tests was 0.02 W/m^2 and the performance drop in irradiation was 0.015 %.

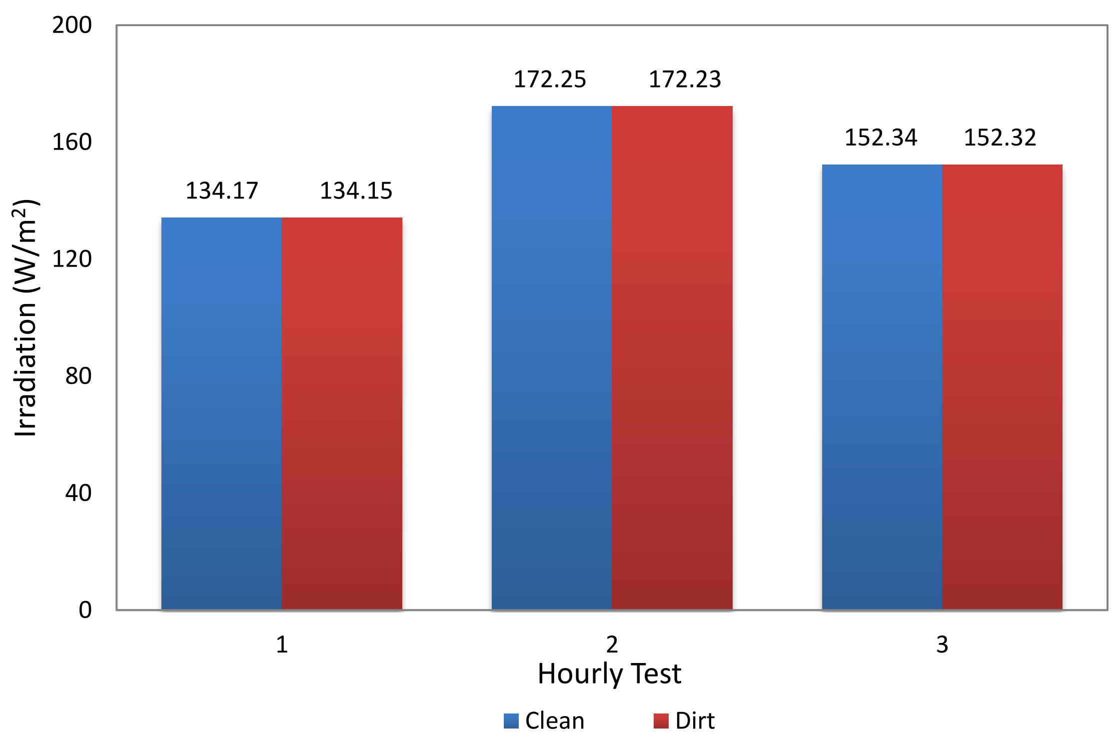


Figure 4.4 Irradiation of clean and dusty panels on hourly test

4.1.5 Summary of Hourly Tests on Power Output

Figure 4.5 shows the summary of all hourly tests on the power output. The blue bar indicates the power output from the clean panel while the red bar indicates the power output from dusty panel. The solar PV panels were used to measure the power output from the clean and dusty panels. From the result, it was found the hourly test two had the highest power output value followed by hourly test 3 and 1. From the result, There was a significant different for the clean and dusty power output especially for the hourly test 1. For the hourly test 1, the different between the clean and dusty panels was 0.03 W and the performance drop from the power output was 0.06 %. For the hourly test 2 and 3, the different in power output was 0.02 W and the reduction of performance for hourly test 2 and 3 was 0.04 %. In overall, the average difference in power output value for clean and dusty panel for all the hourly tests was 0.021 W and the performance drop in irradiation was 0.014 %.

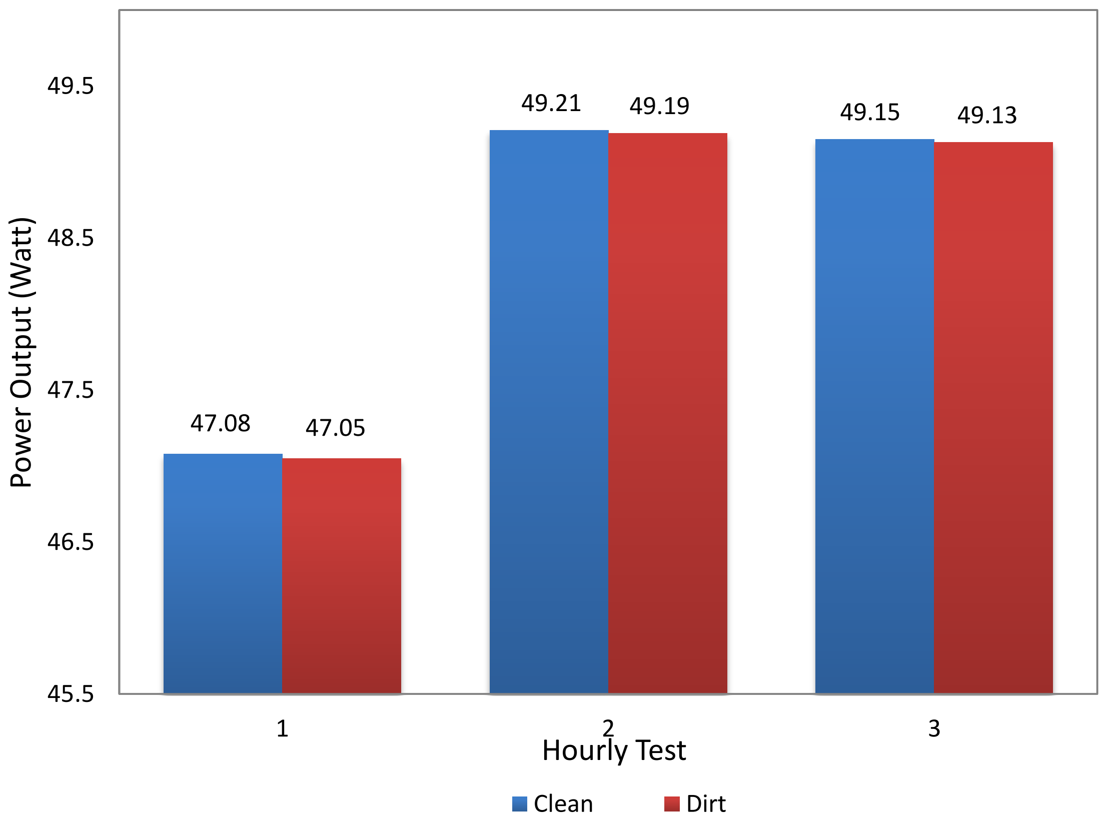


Figure 4.5 Power output for clean and dusty panels on hourly test

4.1.6 Performance Drop of Solar PV Panels on Hourly Test

Figure 4.6 shows the performance drop for irradiation and power output for the daily tests. The performance drop was measured by comparing cleaned panels with dusty pane. It was observed that during conducting all the hourly test, there were no rain and haze at the outside of the building. From obtained result, it was found that hourly test 1 had the highest performance drop of power output and irradiation follow by hourly test 2 and 3. This was due to the amount of dust accumulated on the solar PV panel system for hourly test 1 was higher compared to our test 2 and 3. The higher the amount of dust accumulation on the solar collector give the higher the higher performance drop of the solar PV panel system. Furthermore, the pattern of performance drop of power output and irradiation was the same, however there was a gap between them. It was believed that the efficiency of solar PV collector used was low and that is why it showed a difference in power output. In overall, the average of performance drop of power output was about 0.05 %, while for irradiation were about 0.01% and the average mass of dust accumulated for hourly test was about 0.022 g per 0.01 m^2.

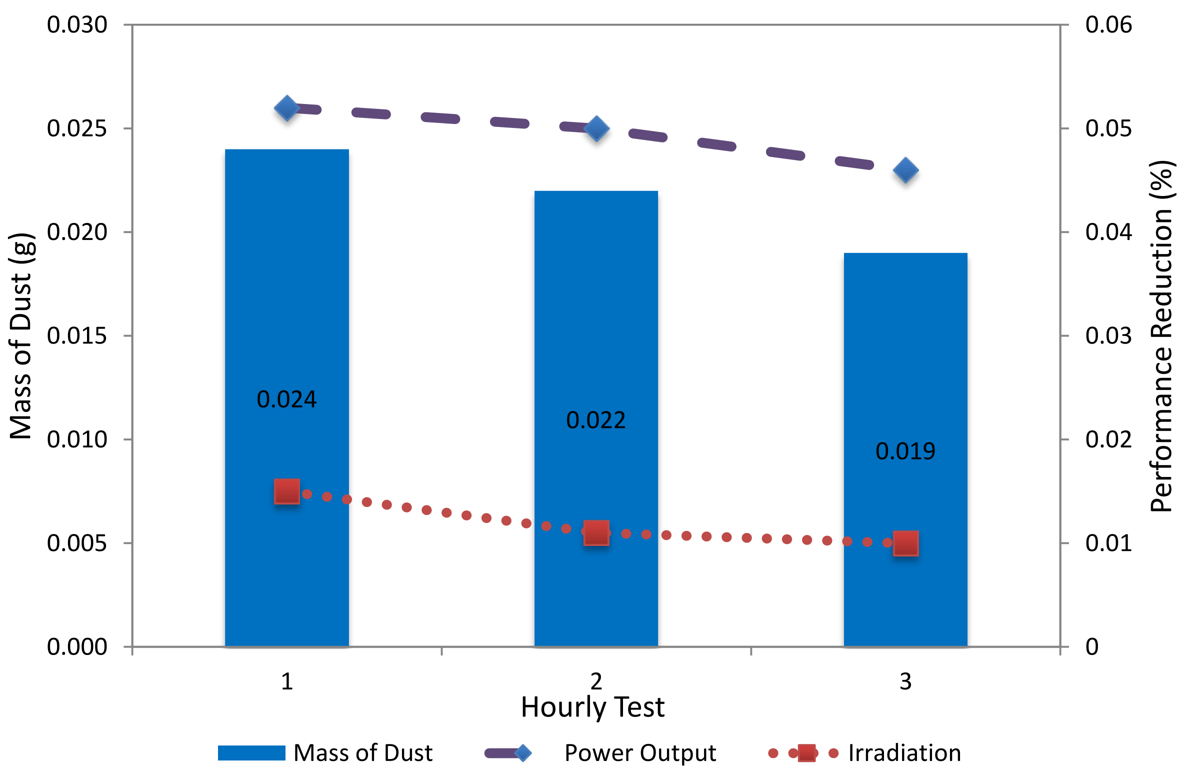


Figure 4.6 Performance reduction with mass of dust on hourly test

4.2 Daily Test

4.2.1 Variation of Power Output and Irradiation with Time on Daily Test

Figure 4.7 shows the variation of power output and irradiation with respect to time for daily test 1. The daily test was conducted three times. The first result of daily test was presented in this section while the rest was presented in the appendices. The first daily test was conducted on 6 May 2014, continue to daily test 2 and 3 on 7 and 8 of May 2014 respectively. It was observed that during conducting all the tests, the weather was fine as there was no rain and haze for three days. The daily tests were conducted from 10 am to 6 pm. There were two pairs of panels which were glass dummy panels and solar PV panels. The first pair of panels were left unclean for one day and the second pair of panels were always cleaned at all times. The reading was taken after letting the dust accumulated in one day without cleaning it. From obtained result, it showed that there was very small different between clean and dusty for power output and irradiation. Furthermore, the variation of power output and irradiation showed the same pattern especially during hour 1 pm to 6 pm.

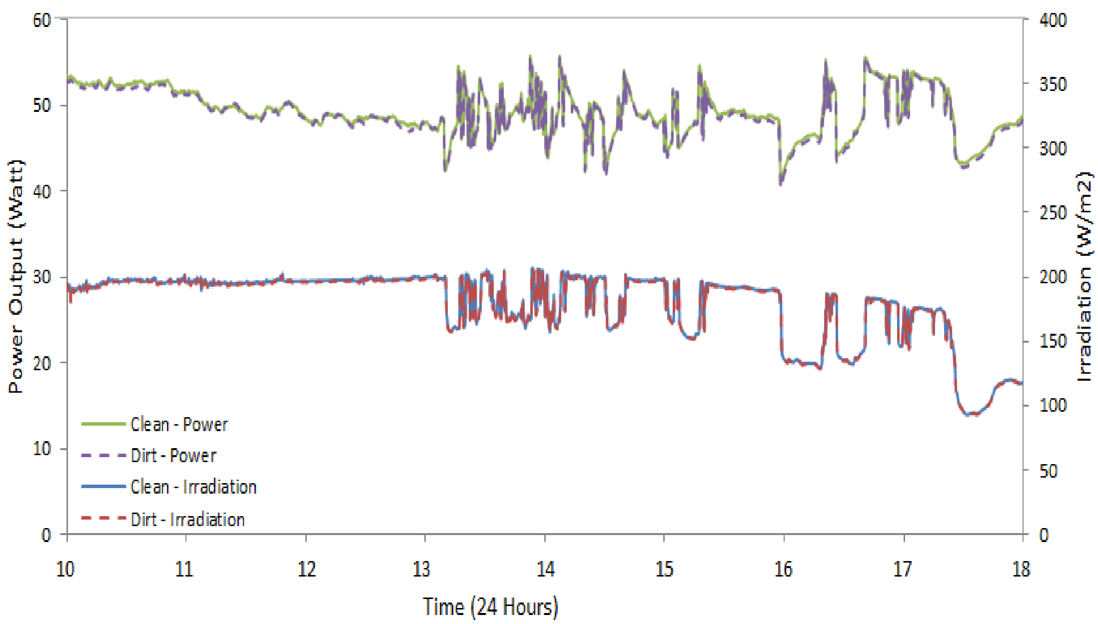


Figure 4.7 Variation of power output and irradiation with time on daily test 1

4.2.2 Variation of Performance Drop with Time on Daily Test

Figure 4.8 shows the variation of performance drop with time for daily test 1. The result, as in Figure 4.8 was derived from the result in Figure 4.9, the variation of power output and irradiation with time. The difference between clean and dusty panels for power output and irradiation was presented in Figure 4.8. The blue line indicates the performance drop of power output while the red line indicates the performance drop of irradiation. From obtained result, it showed that the highest performance drop of power output and irradiation was happening around 2 pm and the less performance drop was occurred 3 pm. This result can be correlated in Figure 4.7 where at 1 pm to 3 pm was the peak sunlight irradiation to the solar collector. On the other hand, the average performance drop of power output was about 0.4 %, while the average performance drop of irradiation was about 0.35 %.

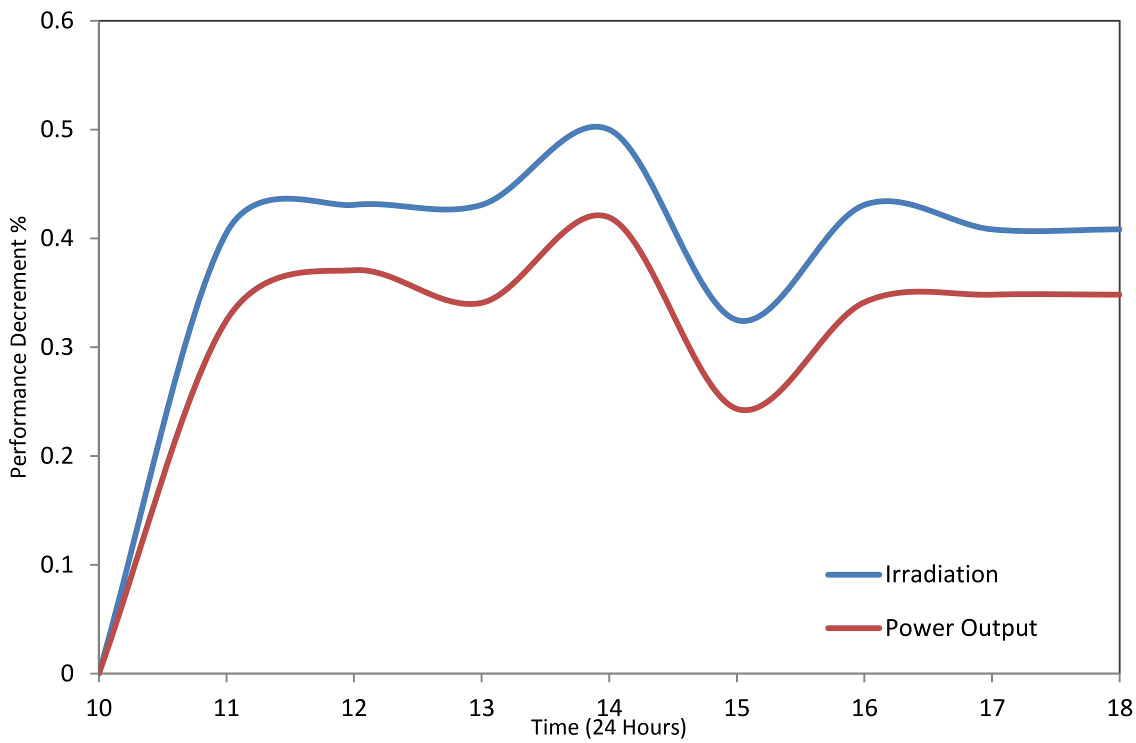


Figure 4.8 Variation of performance drop with time on daily test 1

4.2.3 Summary of Daily Tests on Irradiation

Figure 4.9 shows the summary of all daily tests on the irradiation. The blue bar indicates the irradiation from the clean panel while the red bar indicates the irradiation from dusty pane. The glass dummy panels were used to provide the data in term on sunlight irradiation underneath the glass panels. Daily test 1, 2 and 3 were conducted in 6, 7 and 8 of May 2014 respectively, and the test was conducted from 10 am until 6 pm. It was observed that during conducting the daily tests, the weather was good for every hourly test as there was no rain and haze at outside. From the result, it was found the daily test two had the highest irradiation value compared to daily test 3 and 1. On the other hand, the difference in value of irradiation for clean and dusty panel for hourly test 1 and 2 were the same for all the tests which was 0.9 W/m^2 while test 3 showed 0.6 W/m^2 difference in irradiation value. In summary, the average difference in irradiation value for clean and dusty panel for all the hourly tests was about 0.8 W/m^2.

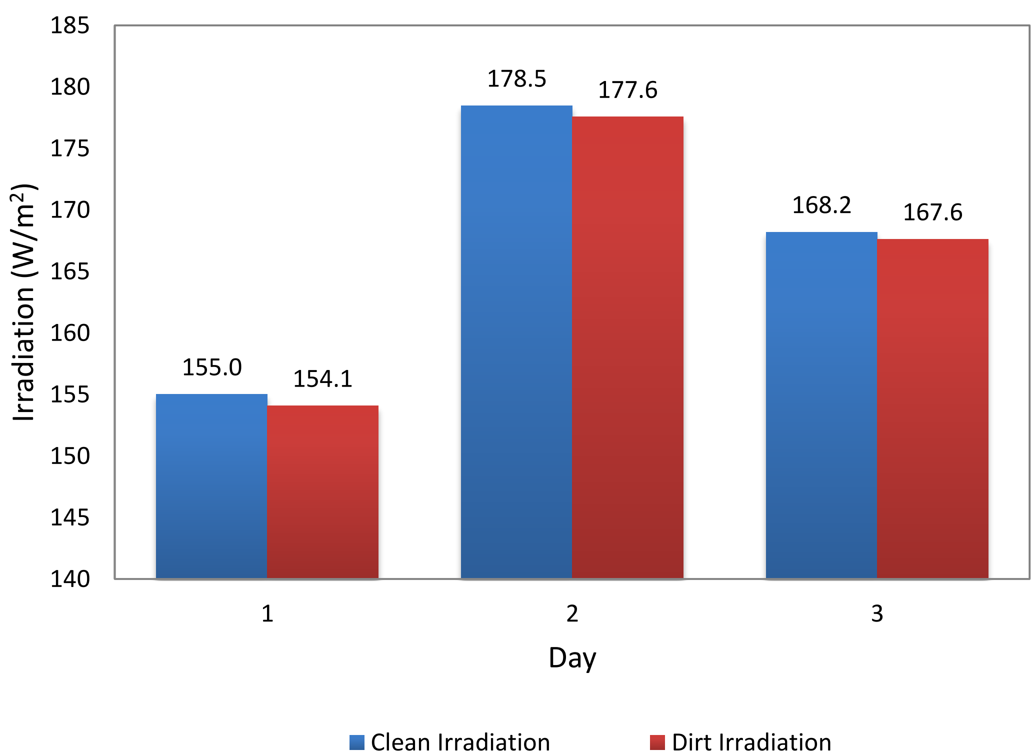


Figure 4.9 Irradiation for clean and dusty panels on daily test

4.2.4 Summary of Daily Tests on Power Output

Figure 4.10 shows the summary of all daily tests on the power output. The blue bar indicates the power output from the clean panel while the red bar indicates the power output from dusty panel. The solar PV panels were used to measure the power output from the clean and dusty panels. From the result, it was found the daily test two had the highest power output value followed by hourly test 3 and 1. From the result, There was a significant different for the clean and dusty power output especially for the daily test 1 and 3. For the daily test 1, the different between the clean and dusty panels was 0.03 W and the performance drop from the power output was 0.61 %. For the hourly test 2 the different in power output was 0.2 W and the performance for was about 0.4 %, for daily test 3, the difference was about 0.3 W and reduction was 0.6 %. In overall, the average difference in power output value for clean and dusty panel for all the daily tests was 0.26 W and the performance drop in irradiation was 0.53 %.

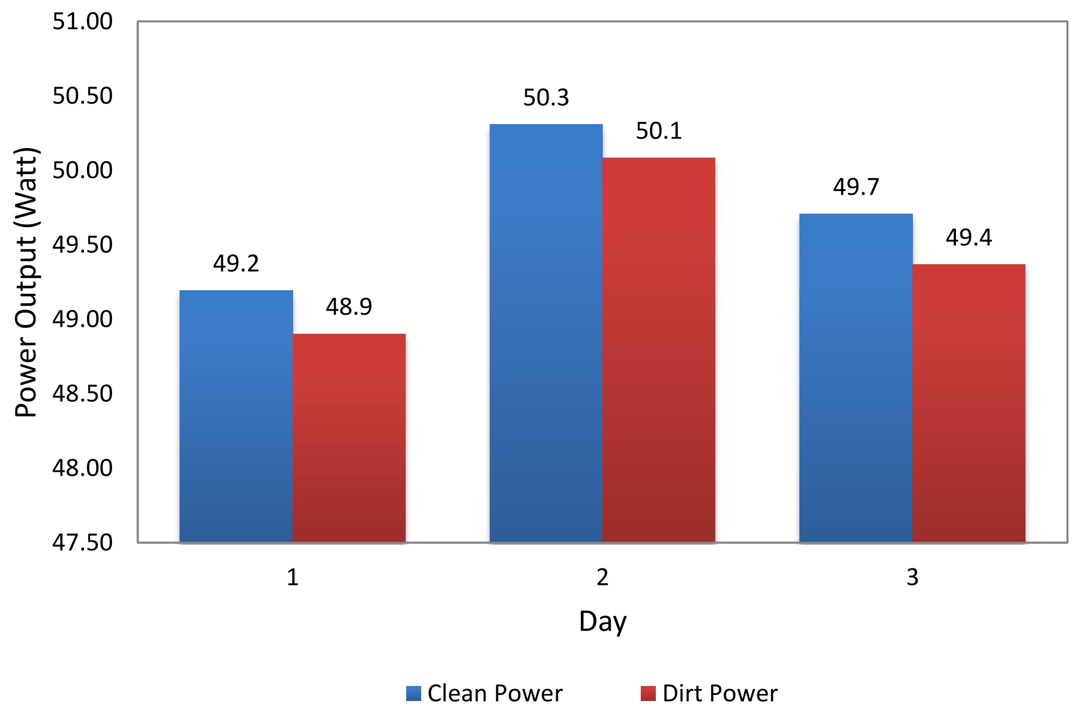


Figure 4.10 Power for clean and dusty panels

4.2.5 Performance Drop of Solar PV Panels on Daily Test

Figure 4.11 shows the performance drop for irradiation and power output for the daily tests. The performance drop was measured by comparing clean panels with dusty pane. It was observed that during conducting all the daily test, there were no rain and haze at the outside of the building. From obtained result, it was found that hdaily test 3 had the highest performance drop of power output and irradiation follow by daily test 1 and 2. This was due to the amount of dust accumulated on the solar PV panel system. Daily test 1 was the highest performance drop compared to daily test 1 and 2. The higher the amount of dust accumulation on the solar collector give the higher the higher performance drop of the solar PV panel system. Furthermore, the pattern of performance drop of power output and irradiation was the same, however there was a gap between them. It was believed that the efficiency of solar PV collector used was low and that is why it showed a difference in power output. In overall, the average of performance drop of power output was about 0.5 %, while for irradiation were about 0.4 % and the average mass of dust accumulated for hourly test was about 0.025 g per 0.01 m^2.

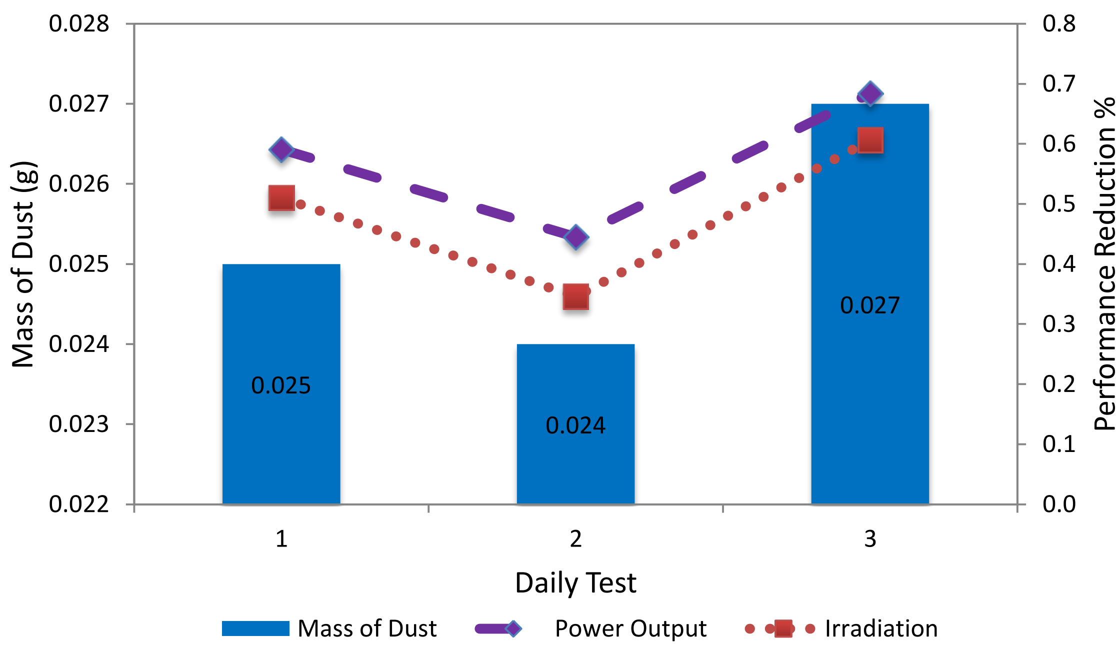


Figure 4.11 Performance reduction and mass of dust on daily test

4.3 Weekly Test

4.3.1 Variation of Power Output and Irradiation with Time on Weekly Test

Figure 4.12 shows the variation of power output and irradiation with respect to time for weekly test 1. The weekly test was conducted three times. The first result of weekly test was presented in this section while the rest was presented in the appendices. The weekly test 1 was conducted on 9 May 2014, weekly test 2 on 16 of May 2014 and weekly test 3 on 8 of June 2014 respectively. It was observed that during conducting all the tests, the weather was good as there was no rain and haze for that days. The weekly tests were conducted from 10 am to 6 pm. Two pairs of panels which were glass dummy panels and solar PV panels was used to measure irradiation and power output. The first pair of panels were left unclean for one week and the second pair of panels were always cleaned at all times. The reading was taken after letting the dust accumulated in one week without cleaning it. From obtained result, it showed that there was a big deviation of power output compared to irradiation for the clean and dusty panels.

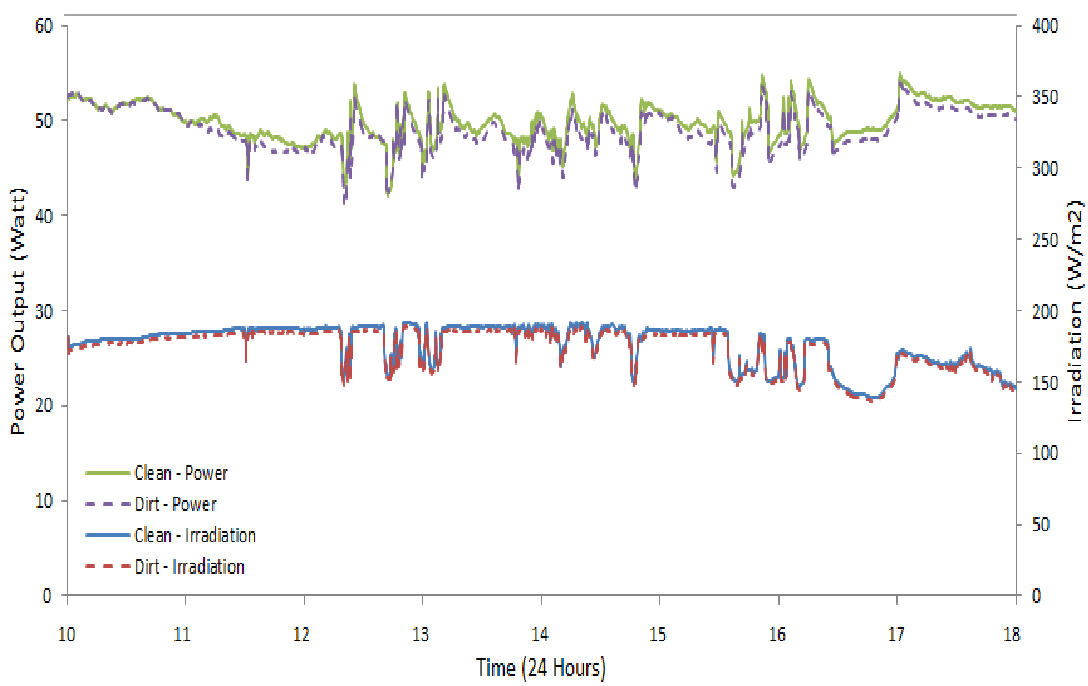


Figure 4.12 Variation of power output and irradiation with time for weekly test 1

4.3.2 Variation of Performance Drop with Time on Weekly Test

Figure 4.13 shows the variation of performance drop with time for weekly test 1. The result, as in Figure 4.13 was derived from the result in Figure 4.12, the variation of power output and irradiation with time. The difference between clean and dusty panels for power output and irradiation was presented in Figure 4.13. The blue line indicates the performance drop of power output while the red line indicates the performance drop of irradiation. From obtained result, it showed that the highest performance drop of power output and irradiation was happening around 4 pm and the less performance drop was occurred 1 pm. On the other hand, the average performance drop of power output was about 0.7 %, while the average performance drop of irradiation was about 0.6 %.

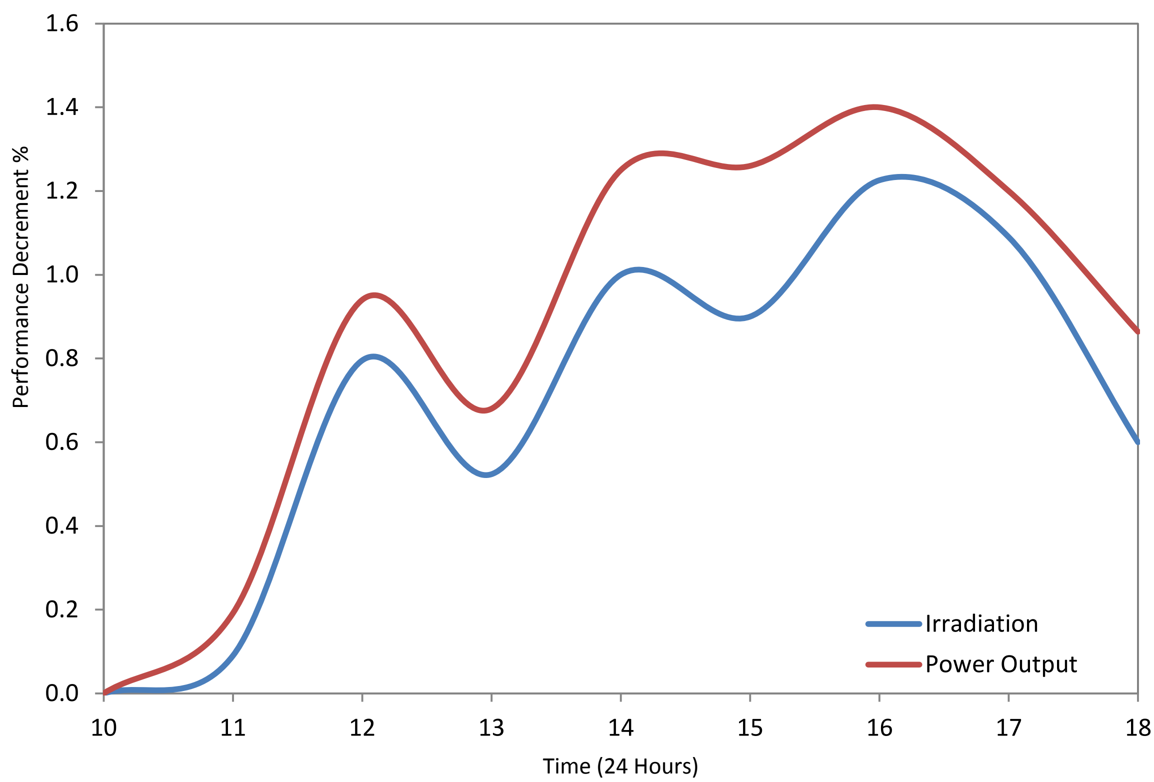


Figure 4.13 Variation of performance drop with time for weekly test 1

4.3.3 Summary of Weekly Tests on Irradiation

Figure 4.14 shows the summary of all weekly tests on the irradiation. The blue bar indicates the irradiation from the clean panel while the red bar indicates the irradiation from dusty pane. The glass dummy panels were used to provide the data in term on sunlight irradiation underneath the glass panels . From the result, it was found the weekly test two had the highest irradiation value compared to daily test 3 and 1. On the other hand, the difference in value of irradiation for clean and dusty panel for the weekly test 1, 2 and 3 were 1.4 W/m^2 , 1.5 W/m^2 and 1.7 W/m^2 In summary, the average difference in irradiation value for clean and dusty panel for all the daily tests was about 1.53 W/m^2.

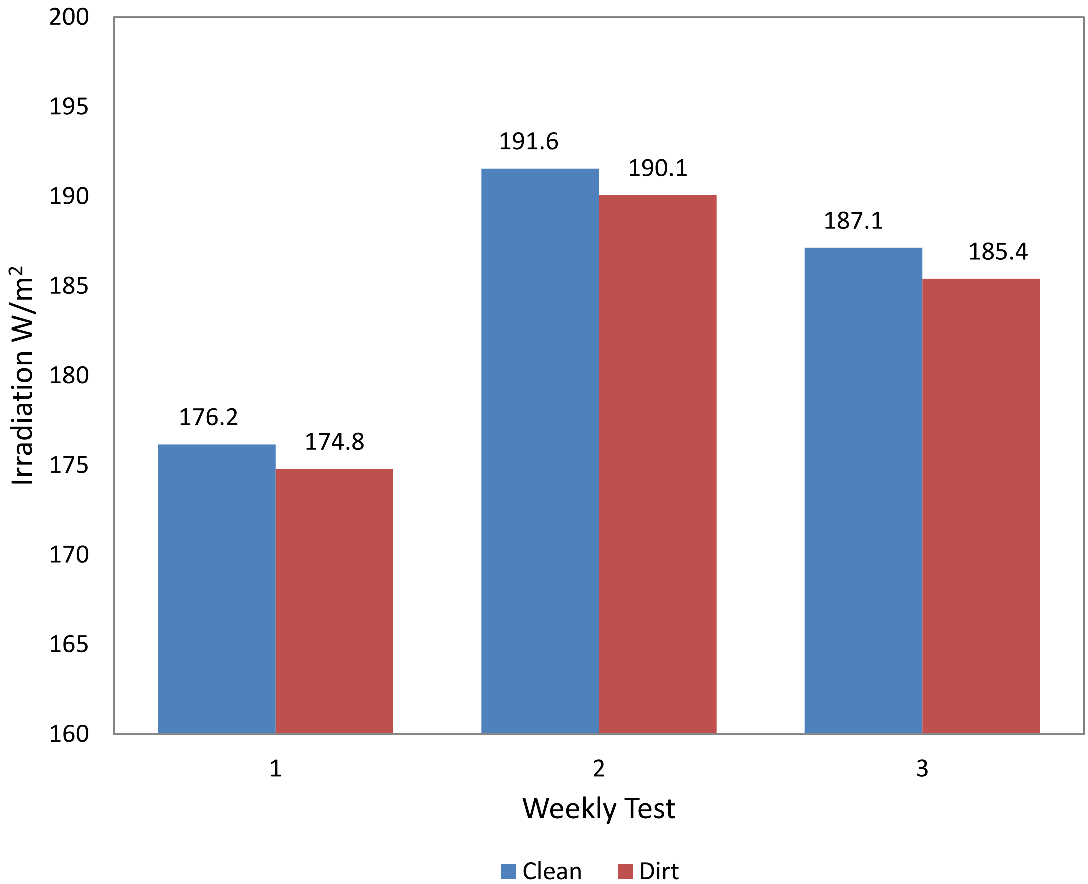


Figure 4.14 Irradiation for clean and dusty panels on weekly test

4.3.4 Summary of Weekly Tests on Power Output

Figure 4.15 shows the summary of all weekly tests on the power output. The blue bar indicates the power output from the clean panel while the red bar indicates the power output from dusty panel. The solar PV panels were used to measure the power output from the clean and dusty panels. From the result, it was found the test two had the highest power output value followed by weekly test 3 and 1. On the other hand, the different in power output between clean and dusty panel for weekly test 1 was 0.5 W weekly test 2 was 0.6 W and weekly test 3 was 0.6 W. In overall, the average difference in power output value for clean and dusty panel for all the hourly tests was about 0.57 W.

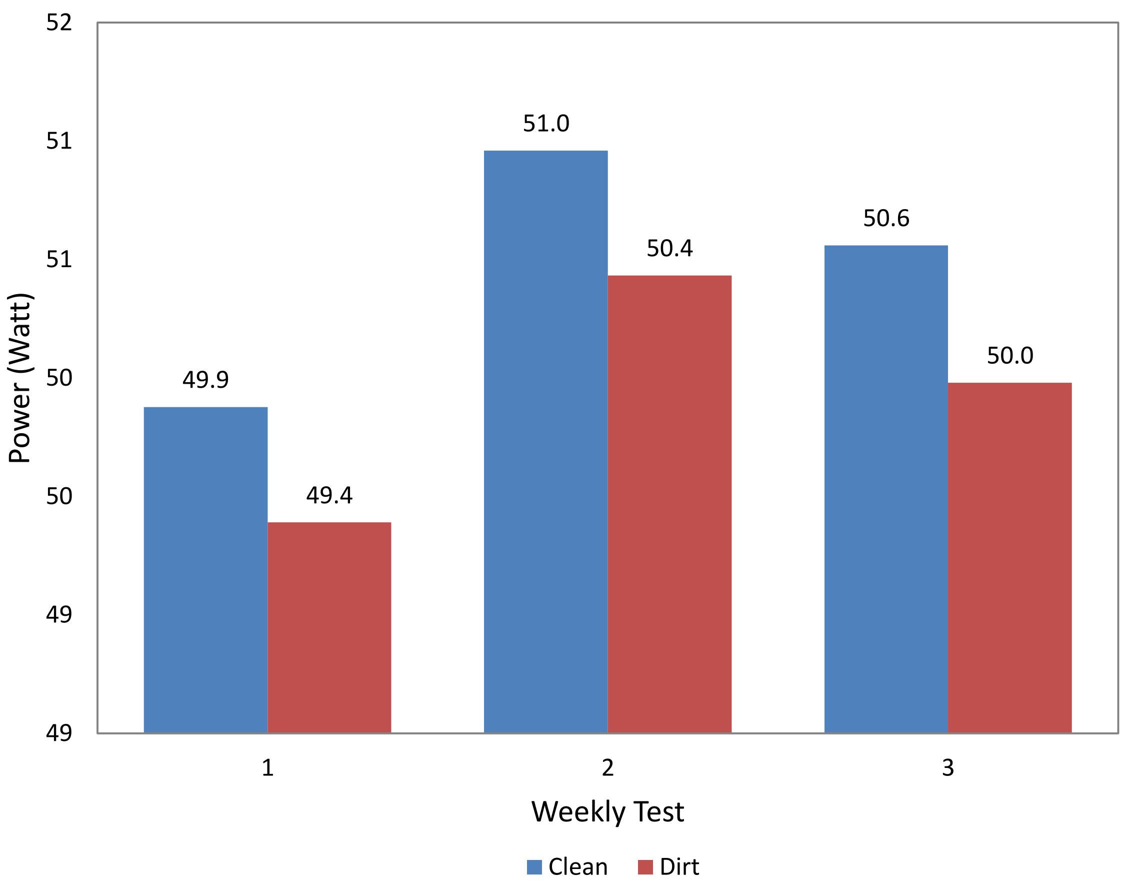


Figure 4.15 Power for clean and dusty panels on weekly test

4.3.5 Performance Drop of Solar PV Panels on Weekly Test

Figure 4.16 shows the performance drop for irradiation and power output for the weekly tests. The performance drop was measured by comparing cleaned panels with dusty pane. It was observed that during conducting all the weekly test, there were no rain and haze at the outside of the building. From obtained result, it was found that hourly test 3 had the highest performance drop of power output and irradiation follow by weekly test 2 and 1. This was due to the amount of dust accumulated on the solar PV panel system for weekly test 1 was higher compared to our test 2 and 3. The higher the amount of dust accumulation on the solar collector will give the higher the higher performance drop of the solar PV panel system. Furthermore, the pattern of performance drop of power output and irradiation was the same. The average of performance drop of power output was about 1.1 %, while for irradiation were about 0.9 % and the average mass of dust accumulated for hourly test was about 0.03 g per 0.01 m^2.

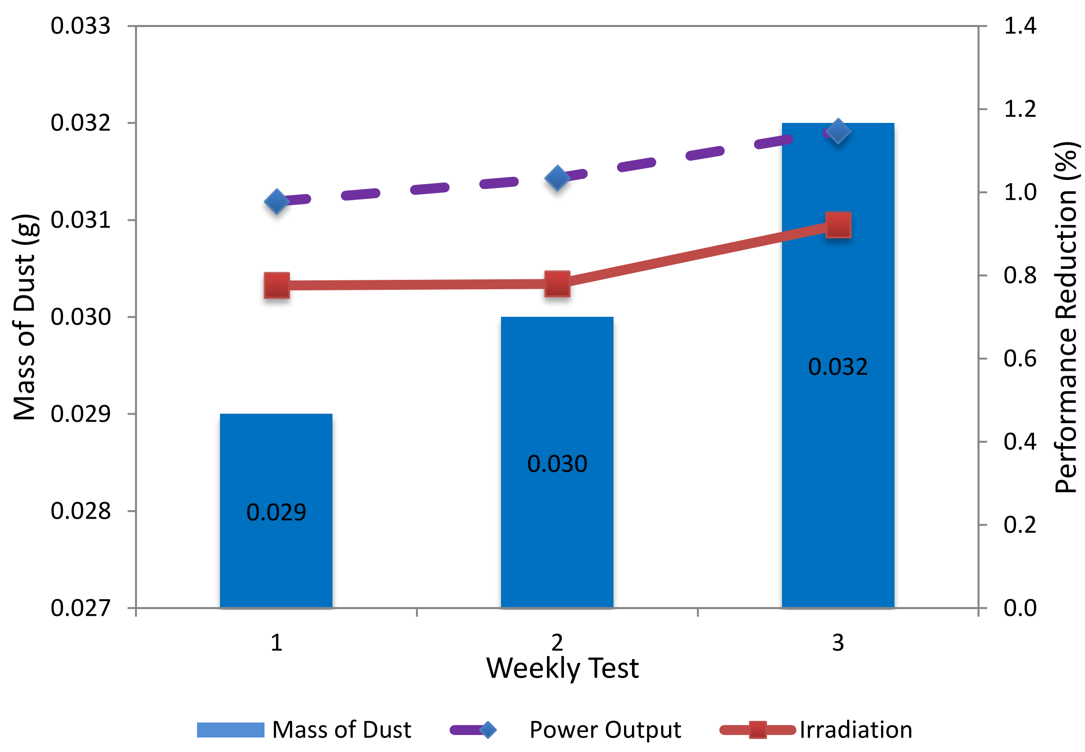


Figure 4.16 Performance reduction and mass of dust on weekly test

4.4 Monthly Test

4.4.1 Variation of Power Output and Irradiation with Time on Monthly Test

Figure 4.17 shows the variation of power output and irradiation with respect to time for monthly test 1. The monthly test was conducted three times. The first result of monthly test was presented in this section while the rest was presented in the appendices. Monthly test 1 was conducted on 30 of April 2014, monthly test 2 on 30 of May 2014 and monthly test 3 on 30 of June 2014. It was observed that during conducting all the tests, the weather was fine as there was no rain and haze for that days. The monthly tests were conducted from 10 am to 6 pm. There were two pairs of panels which were glass dummy panels and solar PV panels. The first pair of panels were left unclean for one month and the second pair of panels were always cleaned at all times. The reading was taken after letting the dust accumulated in one month without cleaning it. From obtained result, it showed that there was a different between clean and dusty for power output and irradiation compare. In overall the average power output of solar PV panel was about 50 W while irradiation was about 180 W/m^2.

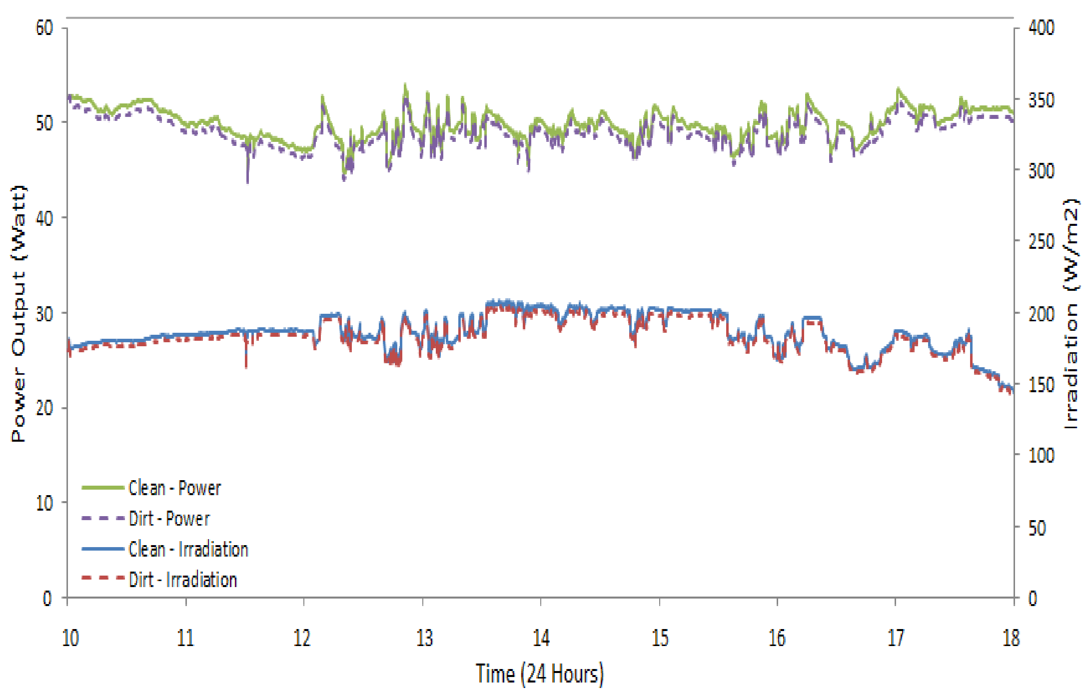


Figure 4.17 Variation of power output and irradiation with time for monthly test 1

4.4.2 Variation of Performance Drop with Time on Monthly Test

Figure 4.18 shows the variation of performance drop with time for montly test 1. The result, as in Figure 4.18 was derived from the result in Figure 4.17, the variation of power output and irradiation with time. The difference between clean and dusty panels for power output and irradiation was presented in Figure 4.18. The blue line indicates the performance drop of power output while the red line indicates the performance drop of irradiation. From obtained result, it showed that the highest performance drop of power output and irradiation was happening around 2 pm and the less performance drop was occurred 12 pm. In summary, the average performance drop of power output was about 1.1 %, while the average performance drop of irradiation was about 0.9 %.

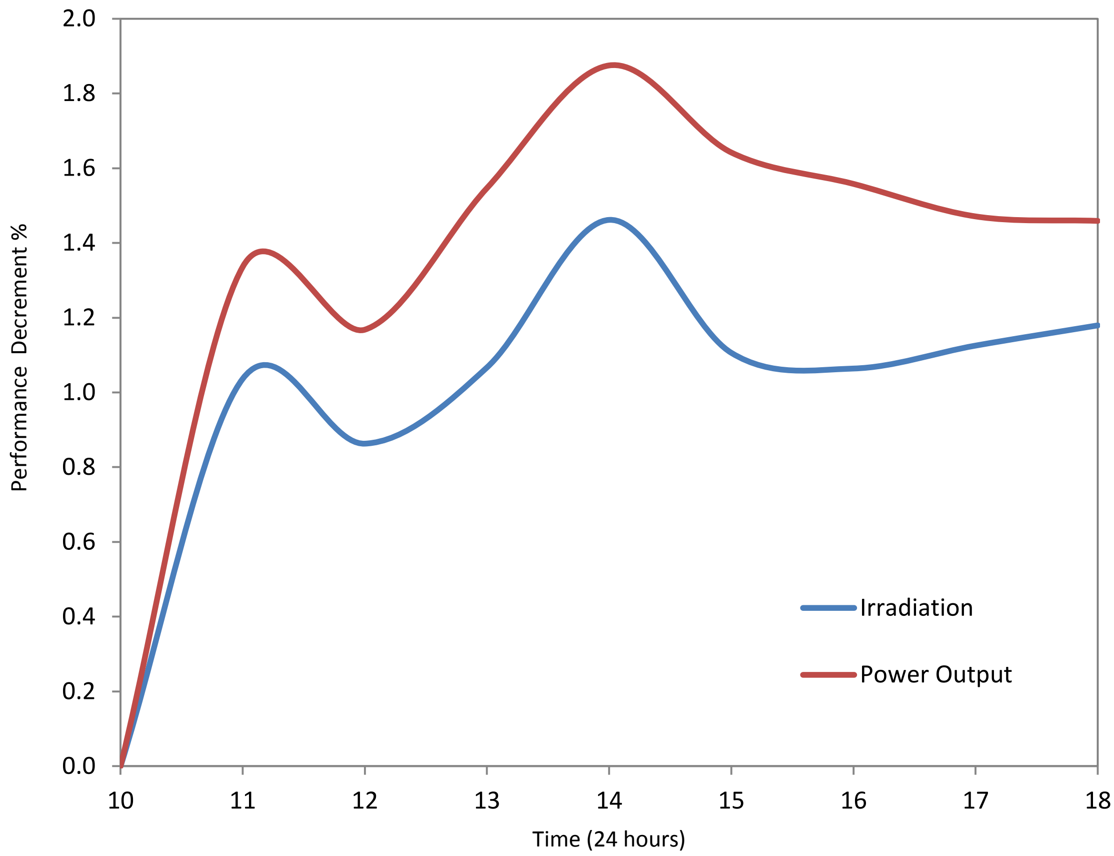


Figure 4.18 Variation of performance drop with time for monthly test

4.4.3 Summary of Monthly Tests on Irradiation

Figure 4.19 shows the summary of all monthly tests on the irradiation. The blue bar indicates the irradiation from the clean panel while the red bar indicates the irradiation from dusty panel. The glass dummy panels were used to provide the data in term on sunlight irradiation underneath the glass panels. It was observed that during conducting the weekly tests, the weather was good for every hourly test as there was no rain and haze at outside. From the result, it was found the weekly test one had the highest irradiation value compared to montly test 2 and 3. On the other hand, the difference in value of irradiation for clean and dusty panel for monthly test 1, 2 and 3 were 2.3 W/m^2, 2.2 W/m^2 and 1.9 W/m^2. In summary, the average difference in irradiation value for clean and dusty panel for all the hourly tests was 2.13 W/m^2.

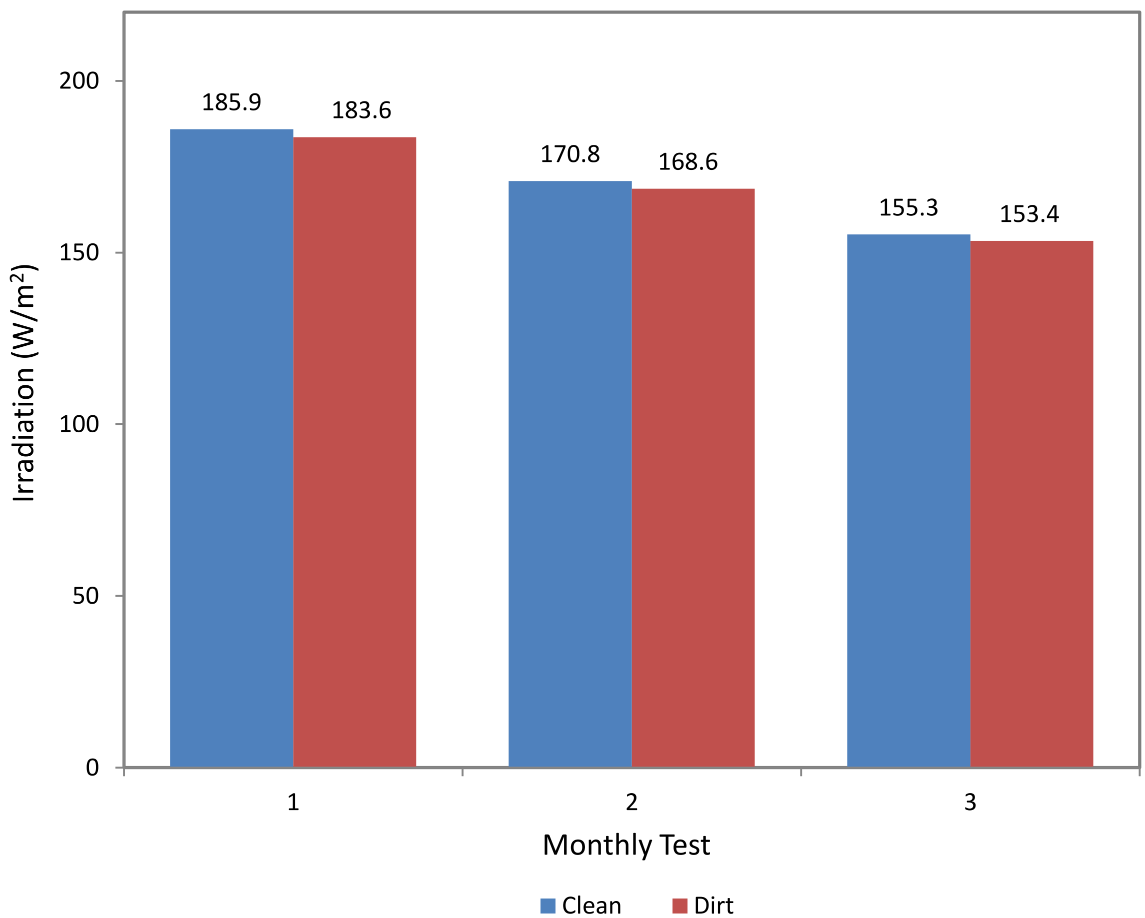


Figure 4.19 Irradiation for clean and dusty panel on monthly test

4.4.4 Summary of Monthly Tests on Power Output

Figure 4.20 shows the summary of all monthly tests on the power output. The blue bar indicates the power output from the clean panel while the red bar indicates the power output from dusty panel. The solar PV panels were used to measure the power output from the clean and dusty panels. From the result, it was found the monthly test one had the highest power output value followed by monthly test 3 and 2. On the other hand, the different between the clean and dusty panels for monthly test 1 was 0.7 W monthly test 2 was 0.8 W and monthly test 3 was 0.8 W. In overall, the average difference in power output value for clean and dusty panel for all the monthly tests was 0.77 W.

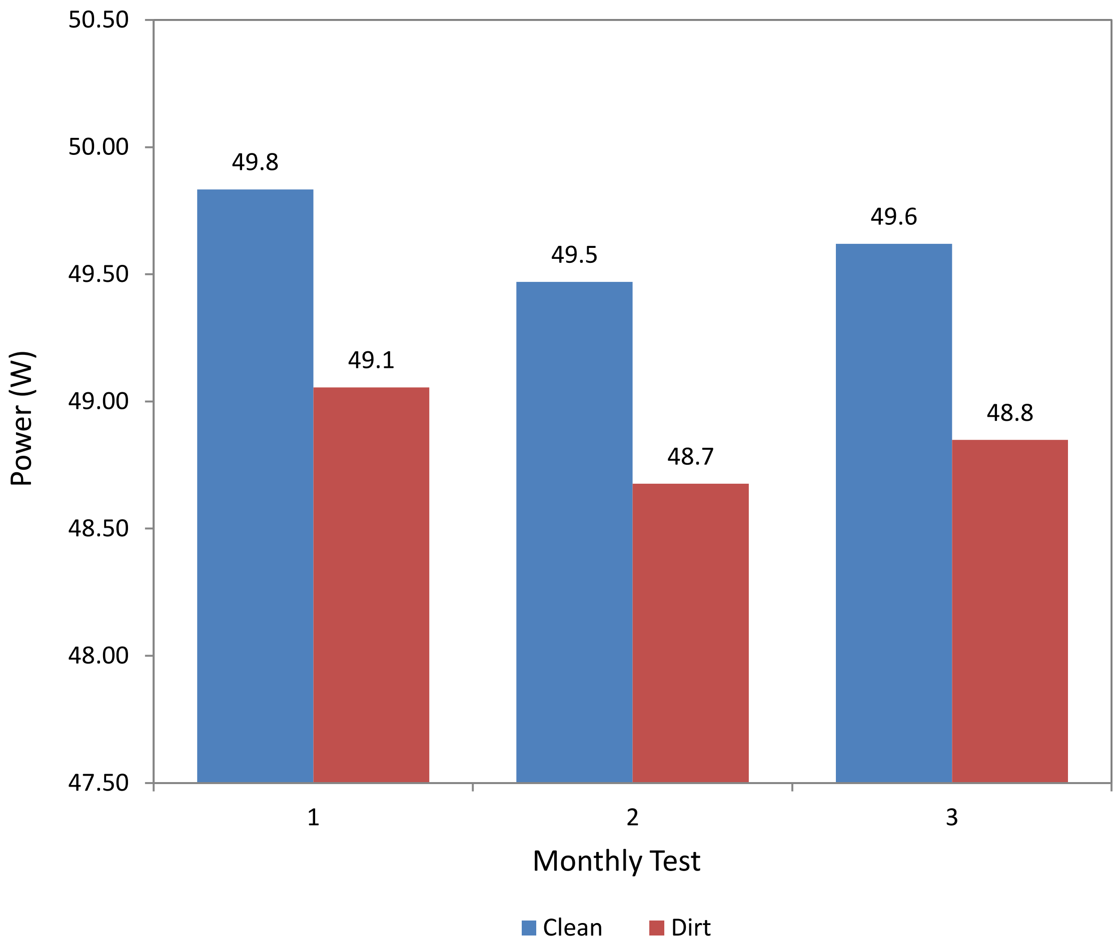


Figure 4.20 Power output for clean and dusty panels for monthly test

4.4.5 Performance Drop of Solar PV Panels on Monthly Test

Figure 4.21 shows the performance drop for irradiation and power output for the monthly tests. The performance drop was measured by comparing cleaned panels with dusty panel. It was observed that during conducting all the hourly test, there were no rain and haze at the outside of the building. From obtained result, it was found that monthly test 2 had the highest performance drop of power output and irradiation follow by hourly test 1 and 3. This was due to the amount of dust accumulated on the solar PV panel system for monthly test 2 was higher compared to our test 1 and 3. The higher the amount of dust accumulation on the solar collector give the higher the higher performance drop of the solar PV panel system. From obtained result, the average of performance drop of power output was about 1.5 %, while for irradiation was about 1.2 % . On the other hand, the average mass of dust accumulated for monthly test was about 0.038 g per 0.01 m^2.

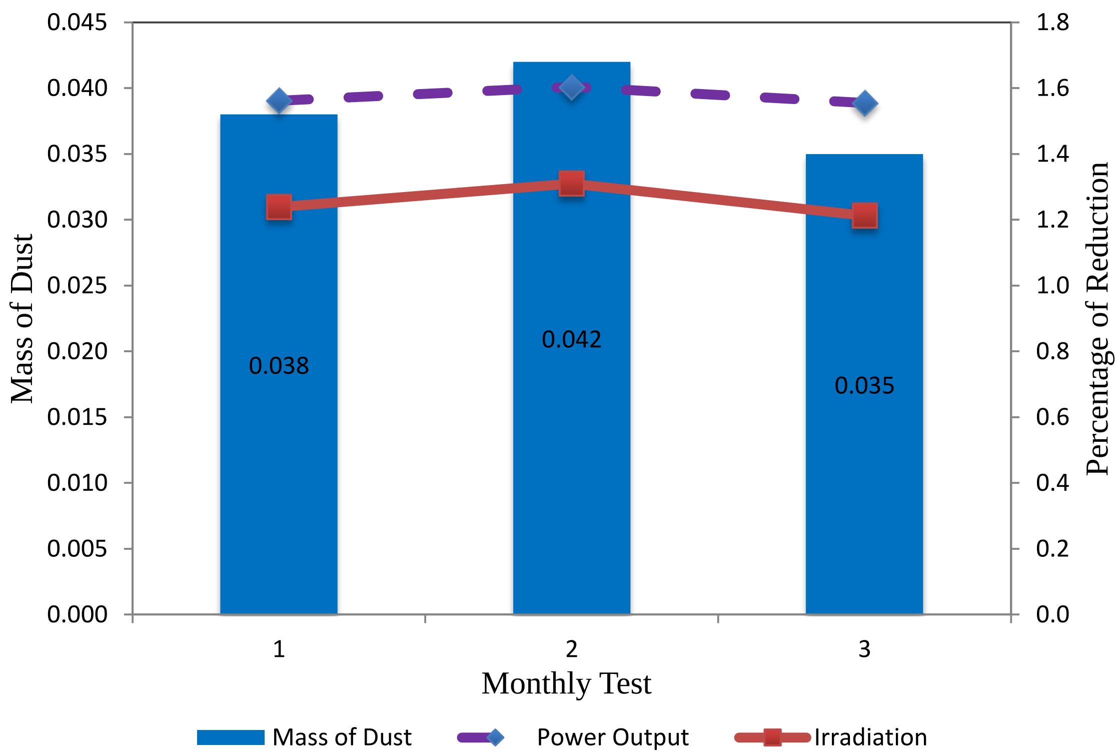


Figure 4.21 Performance reduction and mass of dust on monthly test

4.5 Continously 3 Months Test

4.5.1 Variation of Power Output and Irradiation with Time on 3 Monthly Test

Figure 4.22 shows the variation of power output and irradiation with respect to continuously 3 month. The test was conducted on 1 of July 2014. It was observed that during conducting all the tests, the weather was fine as there was no rain and haze for the day. The tests was conducted from 10 am to 6 pm. There were two pairs of panels which were glass dummy panels and solar PV panels. The first pair of panels were left unclean for 3 months period and the second pair of panels was always be cleaned at all times. The reading was taken after letting the dust accumulated for 3 months period without cleaning it. From obtained result, it showed that there was big a different between clean and dusty for power output and irradiation. In overall, the average irradiation value for the clean panel was about 175 W/m^2 and the dusty panel was about 170 W/m^2.

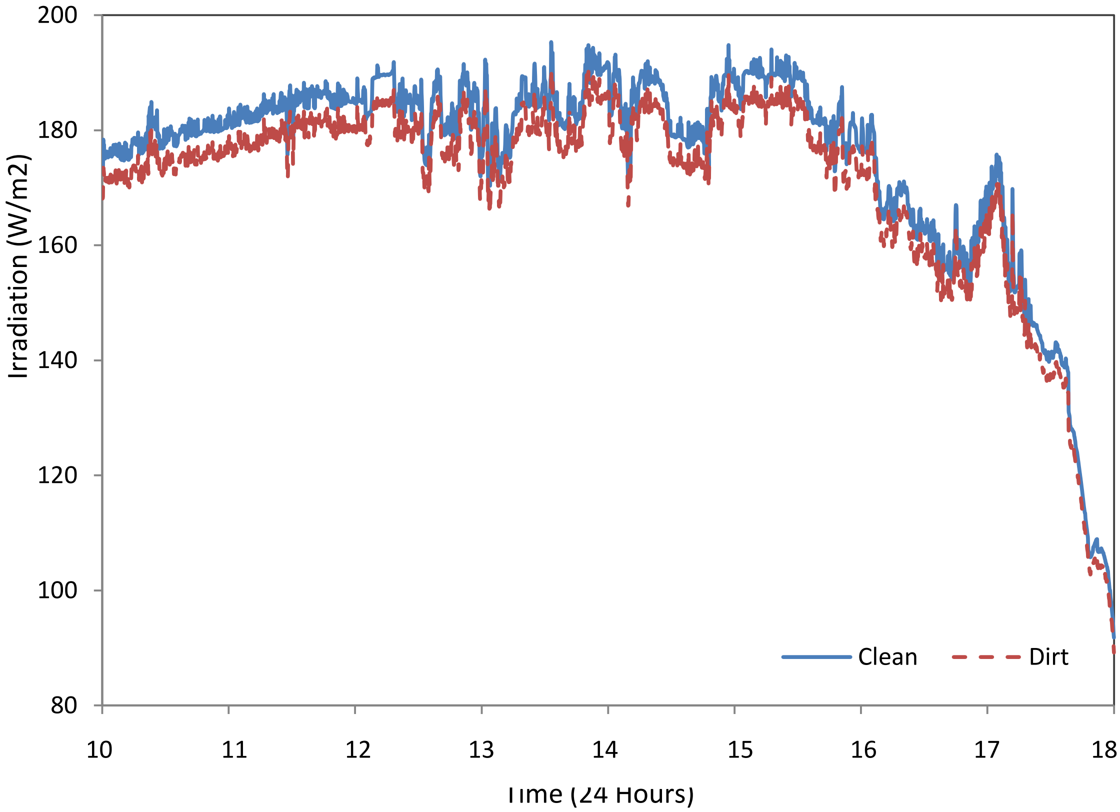


Figure 4.22 Variation of power output and irradiation with time on 3 months

4.5.2 Variation of Performance Drop with Time on Monthly Test

Figure 4.23 shows the variation of performance drop with time for 3 months test. The result, as in Figure 4.23 was derived from the result in Figure 4.24, The difference between clean and dusty panels for the irradiation was presented in Figure 4.8. The blue line indicates the performance drop of irradiation value. From obtained result, it showed that there were 3 peak value of performance drop which were at period of 12 pm, 3 pm and 5 pm. Apart from that, there were two lowest value of irradiaton at period of 2 pm and 4 pm. Furthermore, the average value of peak performance drop was about 2.6 % while the average lowest performance drop was about 2.4 %. In summary, the average performance drop of irradiation for continuously 3 months test was about 2.4 %.

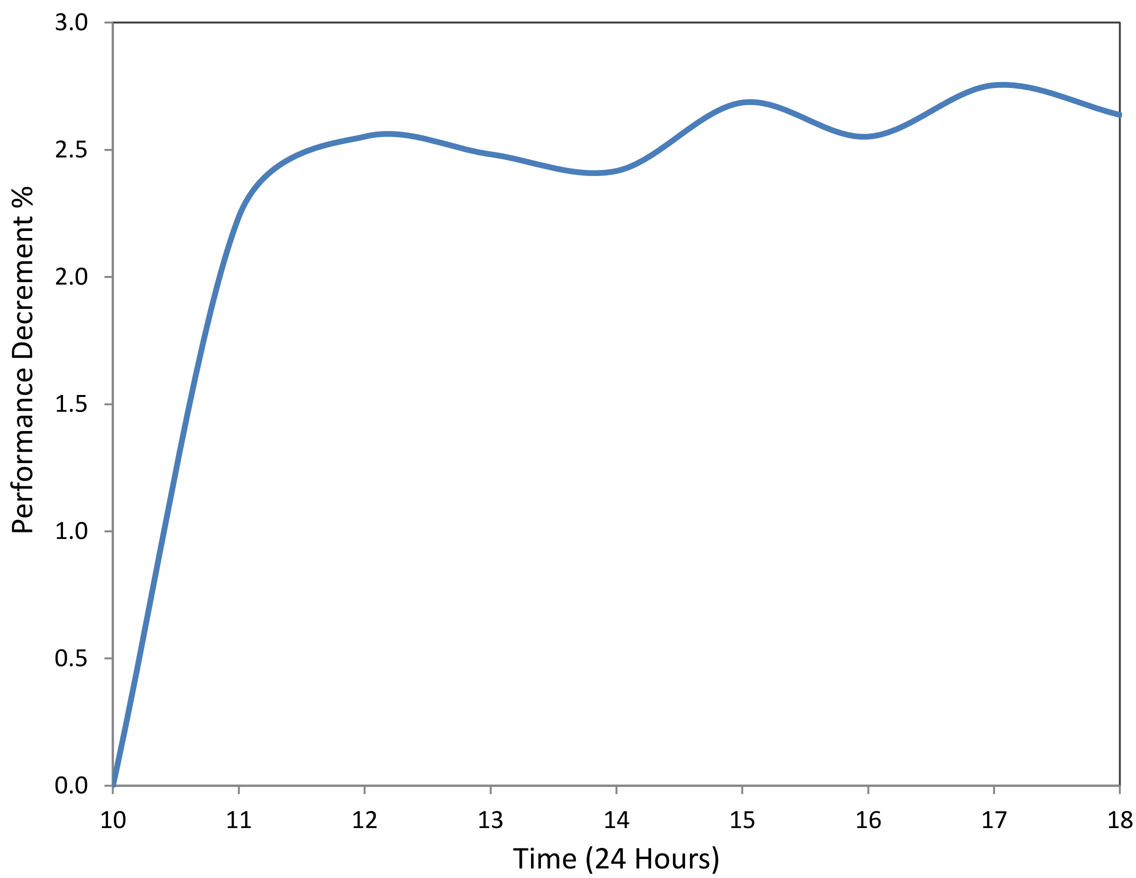


Figure 4.23 Variation of performance drop with tiime on continuous 3 months test

4.6 Summary for All Tests

4.6.1 Performance Drop of Power Output

Figure 4.24 shows the performance drop of power output with respect to different tests. Five different tests were conducted which were hourly, daily, weekly, monthly and continuously 3 month test. All the tests were conducted with the same procedures, however every test was cleaned at different time interval. The hourly test was cleaned at every hour and same goes with daily, weekly, monthly and 3 months tests. From obtained result, it showed that the performance drop of power output was increased from hourly to 3 month test. This was due to the time interval of cleaning time. The hourly test shows smaller drop of power output, which is 0.03 % compared to 3 month test which is 2.54 %. From the result, it shows that the increment of performance drop of power output from hourly to daily test is 0.5 %, daily to weekly test is 0.41 %, weekly to monthly test is 0.47 % and monthly to continuously 3 months test is 1.13 %. In summary, the average performance drop of power output is about 0.46 % from hourly to monthly test.

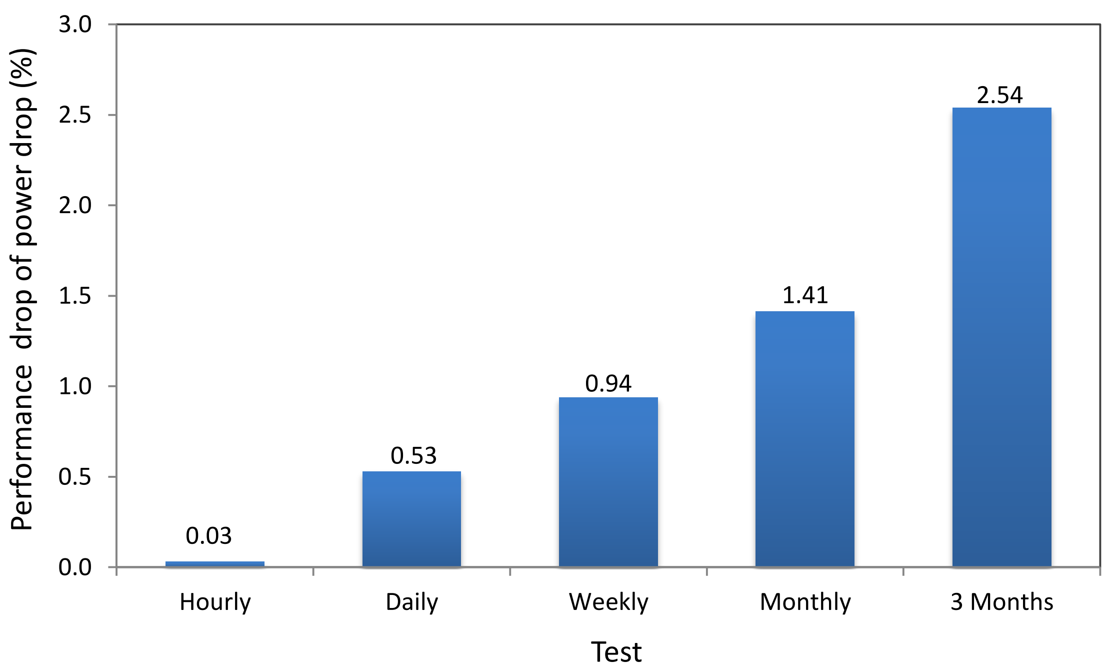


Figure 4.24 Performance of power output drop for all tests

4.6.2 Average Mass of Dust Accumulation

Figure 4.25 shows the average mass of dust accumulation with respect to different tests which are hourly, daily, weekly, monthly and continuously 3 month test. Every test was conducted three times in order to get the total average of dust accumulated on the solar PV collector. Generally two panels of size 0.01 m^2 were used to collect and measure the mass of dust accumulation on the solar collector. The first panel is clean panel while the second panel is dusty panel. The difference in mass between the two panels indicates the mass of dust accumulation on the panel. From obtained result, it shows that the average mass of dust accumulation of the panels is increasing from hourly to 3 month test. This is due to a different interval of cleaning time. The hourly test shows a smaller mass of dust accumulates on the panel, which is 0.03 % compared to 3 month test which is 0.042 %. The increment mass of dust was recorded that hourly to daily test is 0.003 $g/m^{2,}$ daily to weekly test is 0.005 g/m^2, weekly to monthly is 0.008 g/m2, and monthly to continuously 3 month test is 0.004 g/m^2. In summary, the average performance drop of power output is about 0.005 % from hourly to monthly test.

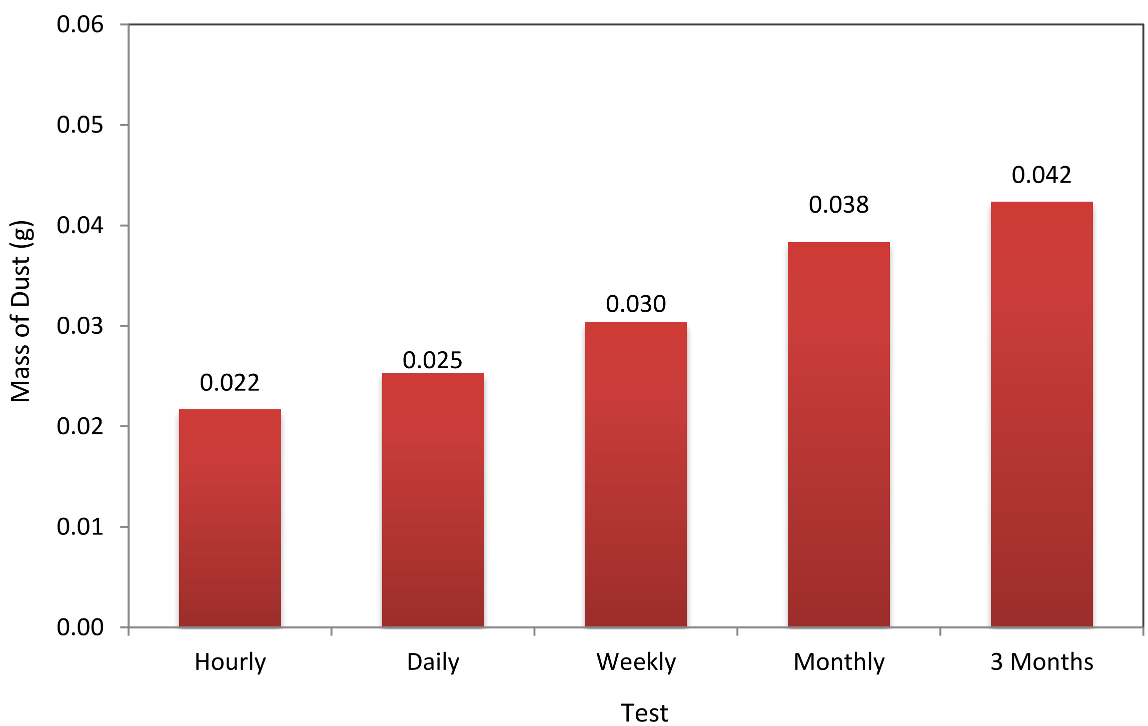


Figure 4.25 Average mass of dust fo all tests

4.7 Proposed Cleaning Maintenance for Industrial and Residential Sectors

4.7.1 Predicted Performance Drop in a Year

Figure 4.26 shows the prediction of performance drop of power output for continuously 3 month test. The first monthly maintenance was indicated that the panels were clean at every month. While the second monthly maintenance indicated that the panel was cleaned in every 2 months and same goes for next following months. From obtained result, it is found that the performance drop for continuously 3 month test increase linearly. Thus, linear extrapolation was made on the graph to predict the performance drop for the next following month. This prediction was used to determine the frequency of maintenance time for both industrial and residential sectors by calculating the profit gain by industrial and residential. The prediction of a power output drop was used in determining the total loss incurred due to drop of solar energy generated from the solar PV panel system.

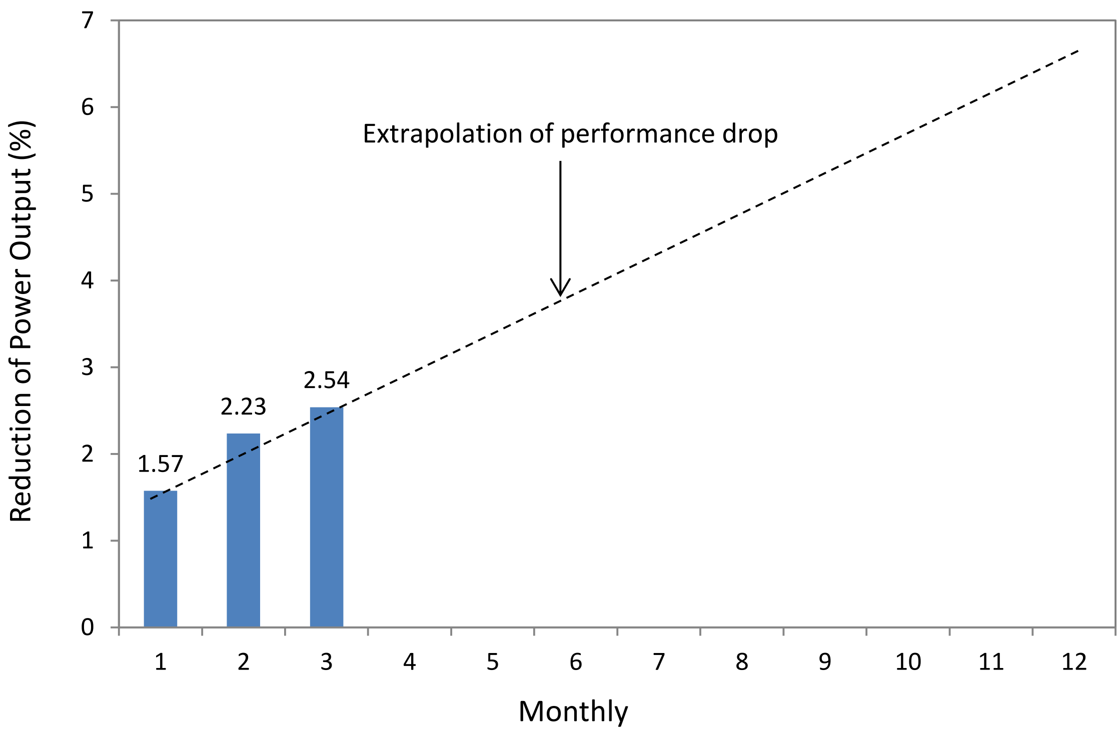


Figure 4.26 Prediction of performance drop of power ouput

4.7.2 Profit Earn by Residental and Individual Sector

Figure 4.27 shows the profit gain by residental and individual sector based on selling producting solar energy to distribution licences like Tenaga Nasional Berhad (TNB) under fit-in tariff scheme. The profit gain by both sector was calculated by taking into account the revenue generated by selling solar energy to distribution licensees, Tenaga Nasional Berhand and the total loss incurred by both sector from performance drop of power ouput, hiring cleaning worker and buying cleaning agent. The detail of calculation can be refered in appendix F. The blue line indicates the profit gain by residential sector while the red line indicates the profit gain by industrial sector. From the prediction of performance drop for every month, it is found that the maximum profit generated from individual sector is about RM 466 per month when the panels is cleaned at every month per year. While for the industrial profit, it is found that the maximum profit is about RM 1,544,007 per month if the panels are cleaned at every two month per year. In overall, it is recommended that individual sector should clean their panels every month while industrial sector should clean their panel at every two months in order to maximize the profit gain from both sector.

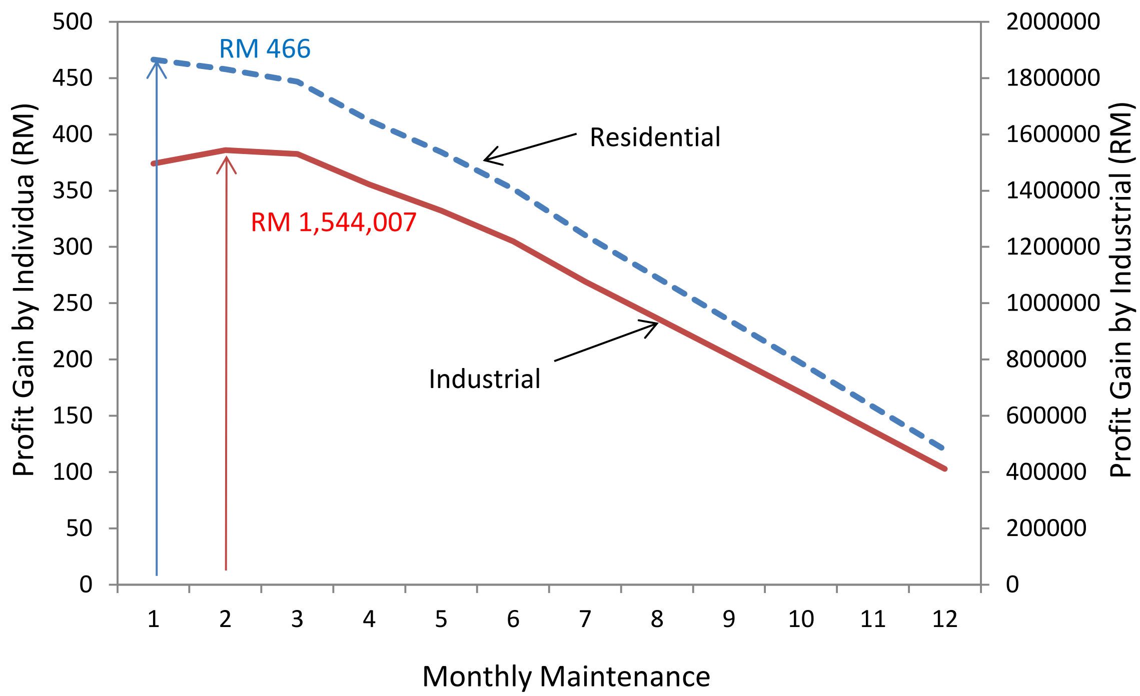


Figure 4.27 Profit gain of two sectors based on montly maintenance

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Solar energy for generation of electrical power through PV panels is advantageous as it is free from environmental pollutions, sustainable and requires low maintenance. However, dust accumulation due to natural causes on solar PV panel can reduce the performance of solar PV system. Studies conducted in different countries showed that accumulated dust on PV panels can reduce performance of the solar power generation system. However there has been no study conducted on the trend of dust accumulation and the frequency of cleaning maintenance of solar panels against dust in Malaysia. To determine the reduction of performance of solar PV panel due to natural causes of dust settlement on solar PV panel, a study of dust accumulation in Malaysia would be required. From the result of this work, the concluding remarks can be made as follows:

1) The reduction of power output from solar PV panel system in Malaysia starts to increase drastically on the clean panels and the rate of reduction increase slowly after hourly test. In addition, the reduction of power output performance from solar PV panel can be reflected to amount of dust accumulate on the solar PV panel surface. The rate of dust accumulates on the solar PV panel in Malaysia also increased drastically on the cleaned panel and it starts to develop slowly on the dusty panels. In addition, the reduction of power output drop from solar PV panel on hourly test was about 0.0307 %, daily test was about 0.5302 %, weekly test was about 0.9391 %, monthly test was about 1.4138 % of and power output drop of continuously 3 months test was about 2.54 %.

2) It was estimated that the performance drop of solar PV panels system in a year was about 6%. Thus by gathering the projected performance drop, the frequency of maintenance time can be made in order to determine the best time to clean their panel for industial and individual sector. On the other hand, for the maintenance of cleaning time, the proposed maintenance of cleaning time for industrial that producing 100 MWh/day should clean their panel at every 2 month time interval in order to maximize the profit generated while for individual sector of producing 20 kWh/day, it is recommended that every month of maintenance time interval is required in order to gain optimum profit of selling solar energy to distribution licesees.

5.2 Recommendations

Improvement on future research is very important to ensure continual improvement on the project can be made from time to time. Future recommendation and improvement can be classified by two categories which are future research and equipment modification. The recommendation of these two categories as follows:

Future Research

1) To study the characteristic and properties of dust accumulation in Malaysia in the near future. By conducting this research, the causes and effects of dust accumulation based on different test can be identified.
2) To conduct experientially on an annual basis for the performance of solar PV panel. Since the present project is not being able to continue on the next following month due to time limitation. Thus, it is good to continue for a year basis in order to verify the result of the predicted performance drop of power output with respect to monthly maintenance.

Equipment Modification

1) The measuring scale of sensitivity of more than 0.001 g should be used for dust measurement in order to get very accurate data on mass of dust.
2) More tests should be conducted (5 times) in order get very accurate results.

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Appendix A: Experimental Apparatus

<table>
<tr><td>EQUIPMENT</td><td>Solar PV Panel
</td><td>Glass Panel
</td><td>Precision Balance
</td></tr>
<tr><td>DESCRIPTION</td><td>It is used to measure power output generated from PV panel</td><td>It is used to measure the sun light irradiation coming to the surface</td><td>It is used to measure mass of dust</td></tr>
<tr><td>SPECIFICATION</td><td>Module Type
Monocrystalline

Dimension
780mm × 550 mm

Peak Power
45.9 W

Peak Power Voltage
16.3 V

Peak Power Current
2.08 A

Short Circuit Current
3.1 A

Open Circuit Voltage
21.3 A</td><td>Glass Type
Tempered

Dimension
780mm×550 mm

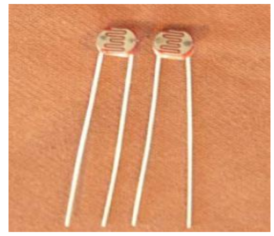
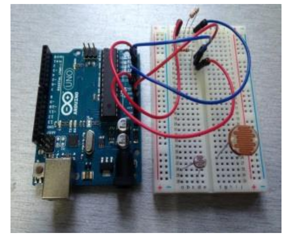
Thickness
6mm</td><td>Brand
Toledo ME 3002E

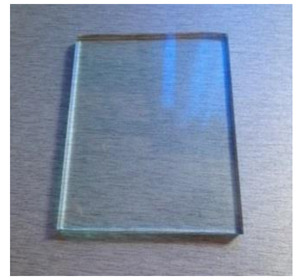
Max Capacity
3200g

Readibility
0.01g

Linearlity
0.02 g

Dimension Width
200 mm</td></tr>
<tr><td>QUANTITY</td><td>3</td><td>3</td><td>1</td></tr>
</table>

EQUIPMENT	**Power Meter Data Logger** 	**Light Dependent Resistance (LDR)** 	**Light Meter Data Logger** 
DESCRIPTION	It is used to record and save the data of power output from PV panel	It is probe to measure the sun light irradiation	It is used to process the data for sunlight irradiation
SPECIFICATION	**Analog Input** 10 Channels **Internal Memory** 2 GB **Operating Environment** $0^{\circ}C$ to $45^{\circ}C$ 5% to 85% RH	**Light Resistance 10 Lux** 8 to 20 KOhm **Dark Resistance at 0 Lux** 1 MOhm(Min) **Ambient Temperature** $-30^{\circ}C$ to $70^{\circ}C$	**Microcontroller** ATmega328 **Operating Voltage** 5V **Input Voltage** 7-12 V
QUANTITY	1	2	1

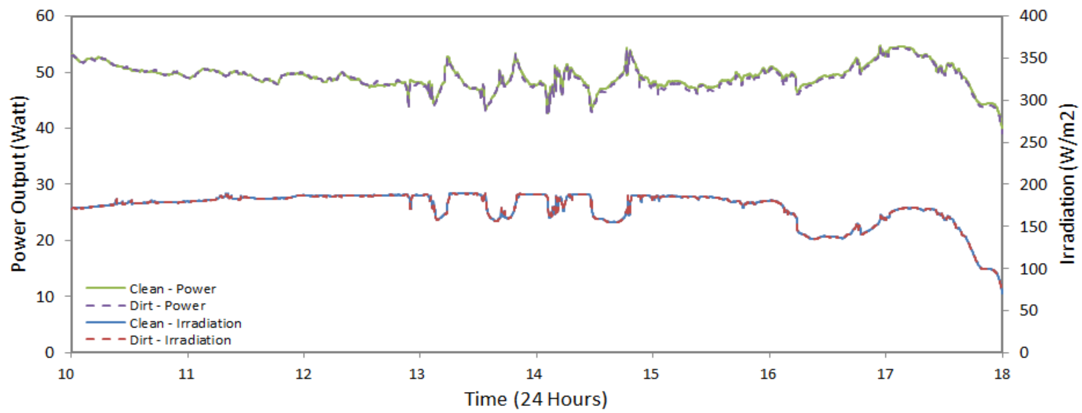
EQUIPMENT	**Laptop** 	**Small Glass** 
DESCRIPTION	Light irradiation and power output data would directly stored in the laptop	It is used to measure the dust accumulation on the surface
SPECIFICATION	**Brand** Aspire V5 Series **Model No** MS2381 **Operating System** Window 8 **DC Rating** 19 V **AC Rating** 2.15 A	**Glass Type** Tempered Glass **Dimension** 100mm×100mm **Thickness** 6mm
QUANTITY	1	3

Appendix B : Programming Code of Solarimeter

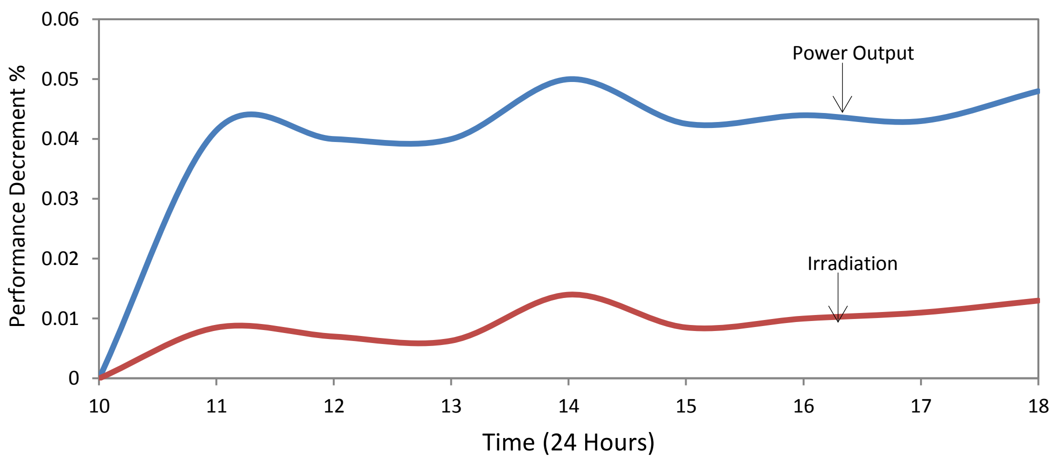
```
// number of analog samples to take per reading
#define NUM_SAMPLES 10

int sum = 0;                    // sum of samples taken
unsigned char sample_count = 0; // current sample number
float voltage = 0.0;            // calculated voltage

void setup()
{
    Serial.begin(9600);
}

void loop()
{
    // take a number of analog samples and add them up
    while (sample_count < NUM_SAMPLES) {
        sum += analogRead(A2);
        sample_count++;
        delay(10);
    }
    // calculate the voltage
    // use 5.0 for a 5.0V ADC reference voltage
    // 5.015V is the calibrated reference voltage
    voltage = ((float)sum / (float)NUM_SAMPLES * 5.015) / 1024.0;
    // send voltage for display on Serial Monitor
    // voltage multiplied by 11 when using voltage divider that
    // divides by 11. 11.132 is the calibrated voltage divide
    // value
    Serial.print(voltage * 11.132);
   Serial.println ("V");
    sample_count = 0;
    sum = 0;
}
```

Appendix C : Hourly Test

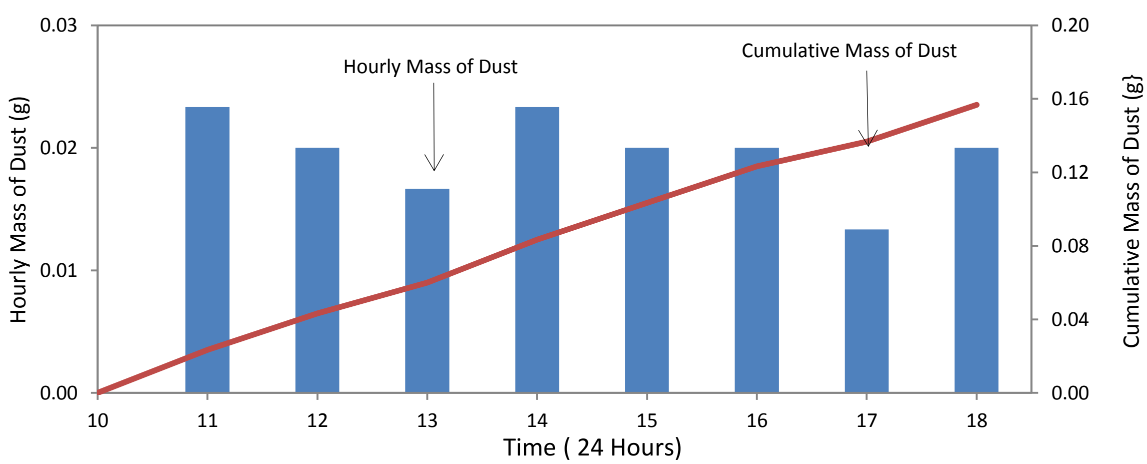
Hourly Test 2



Variation of power output and irradiation with time for hourly test 2

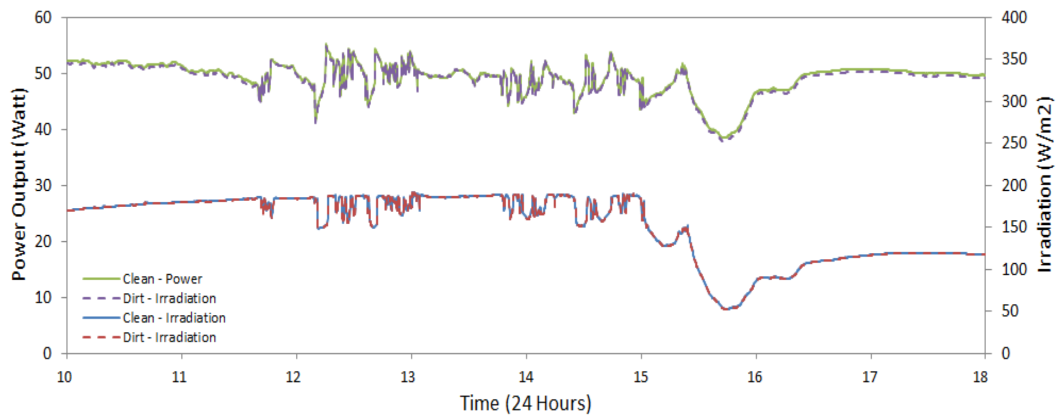


Variation of performance drop with time on hourly test 2

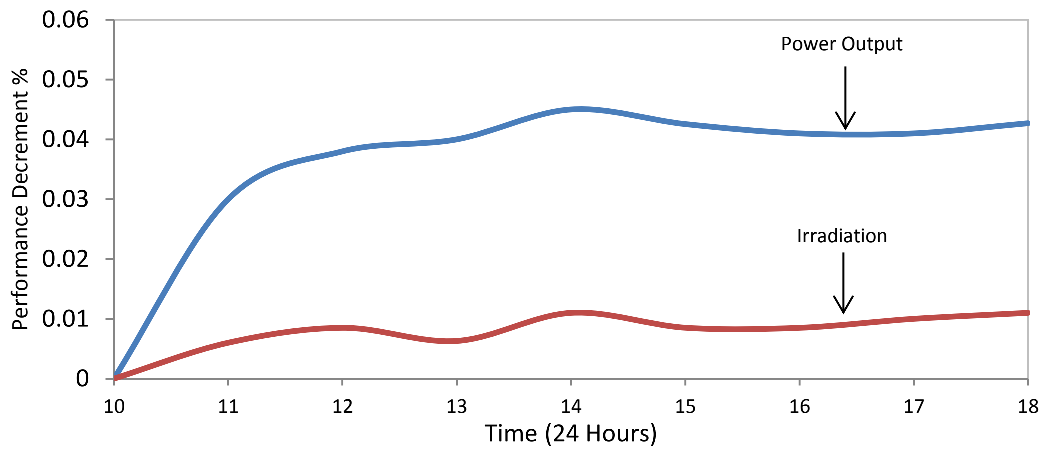


Distribution mass of dust with time on hourly test 2

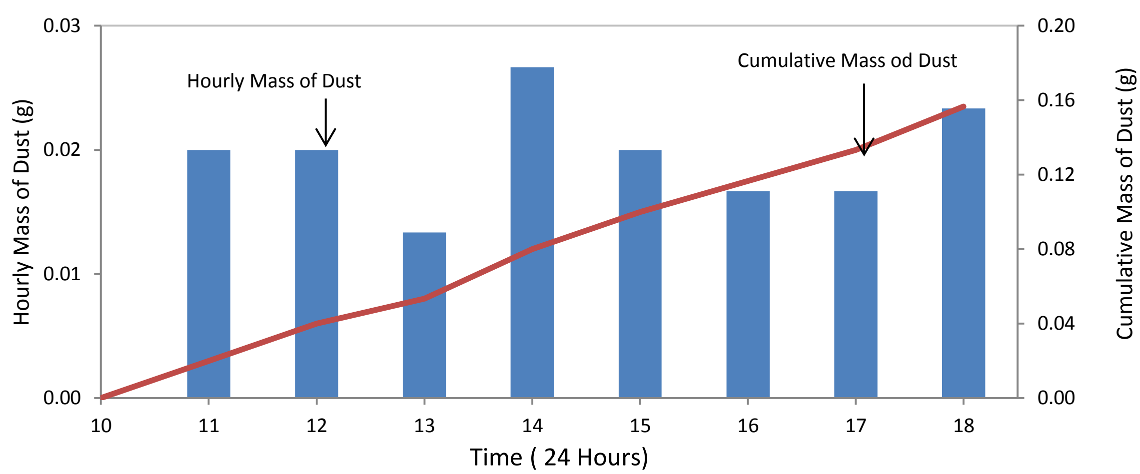
Hourly Test 3



Variation of power output and irradiation with time for hourly test 3



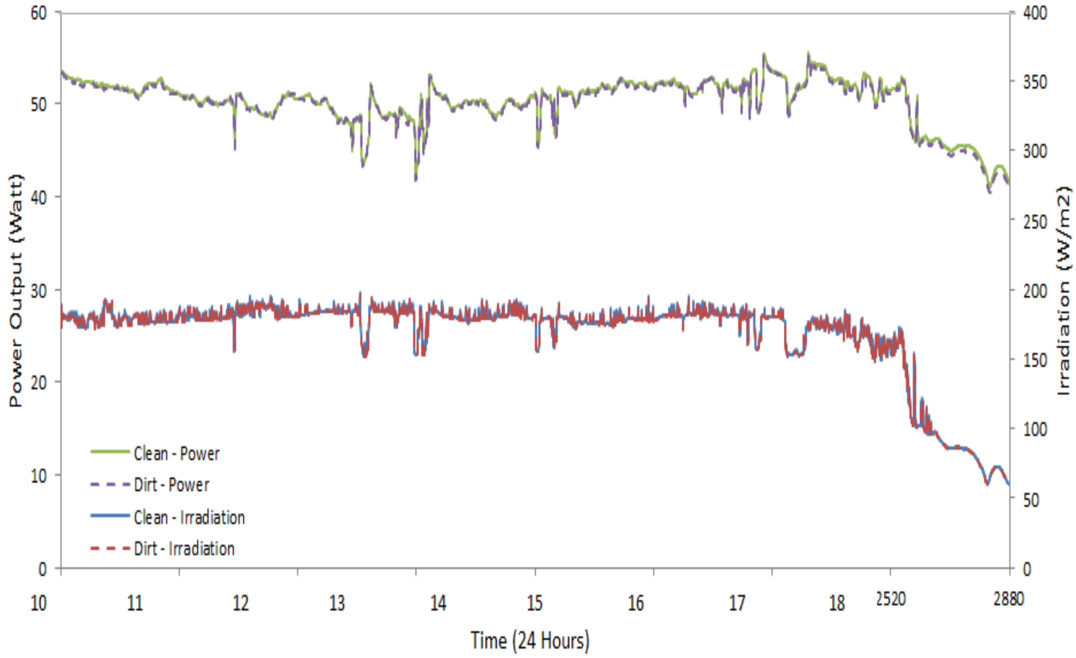
Variation of performance drop with time on hourly test 3



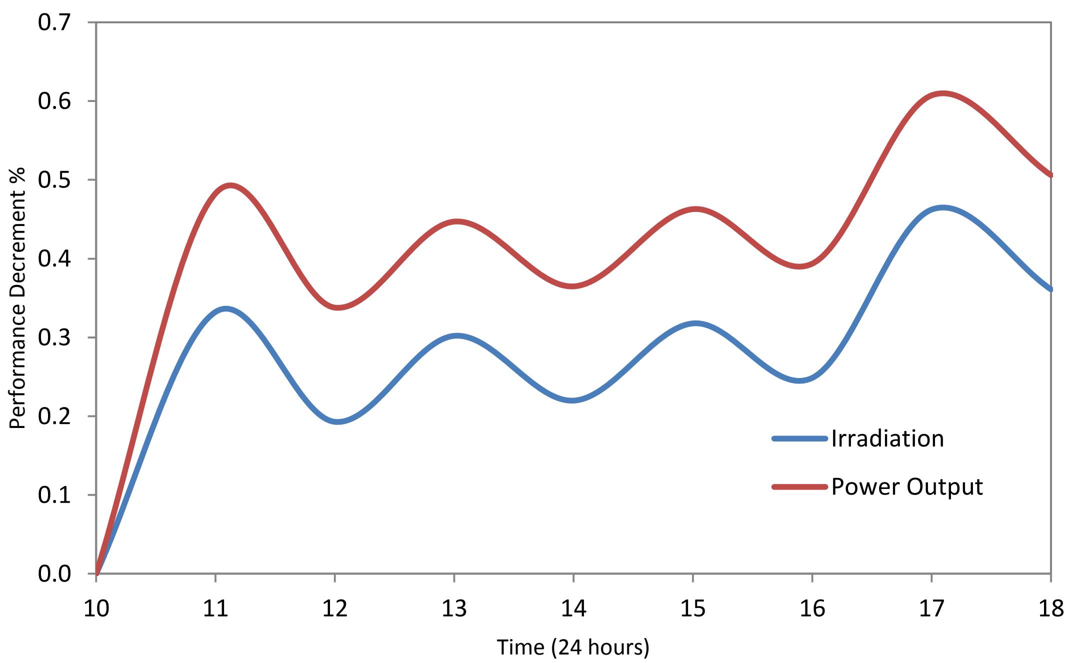
Distribution mass of dust with time on hourly test 3

Appendix C : Daily Test

Daily Test 2

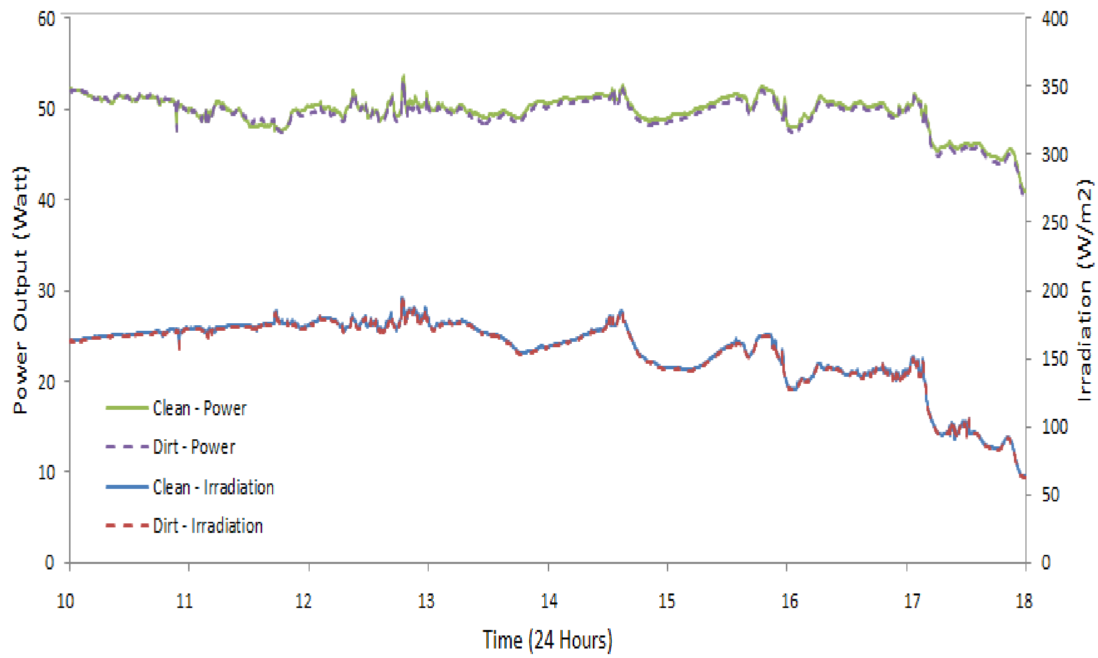


Variation of power output and irradiation with time on daily test 2

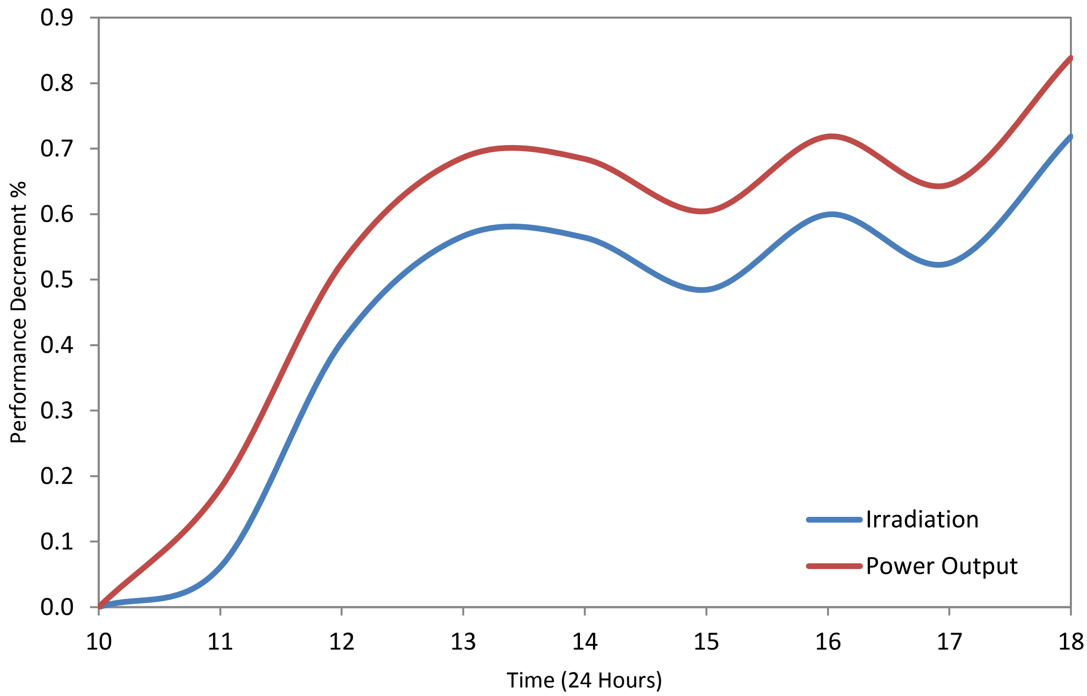


Variation of performance drop with time on daily test 2

Daily Test 3



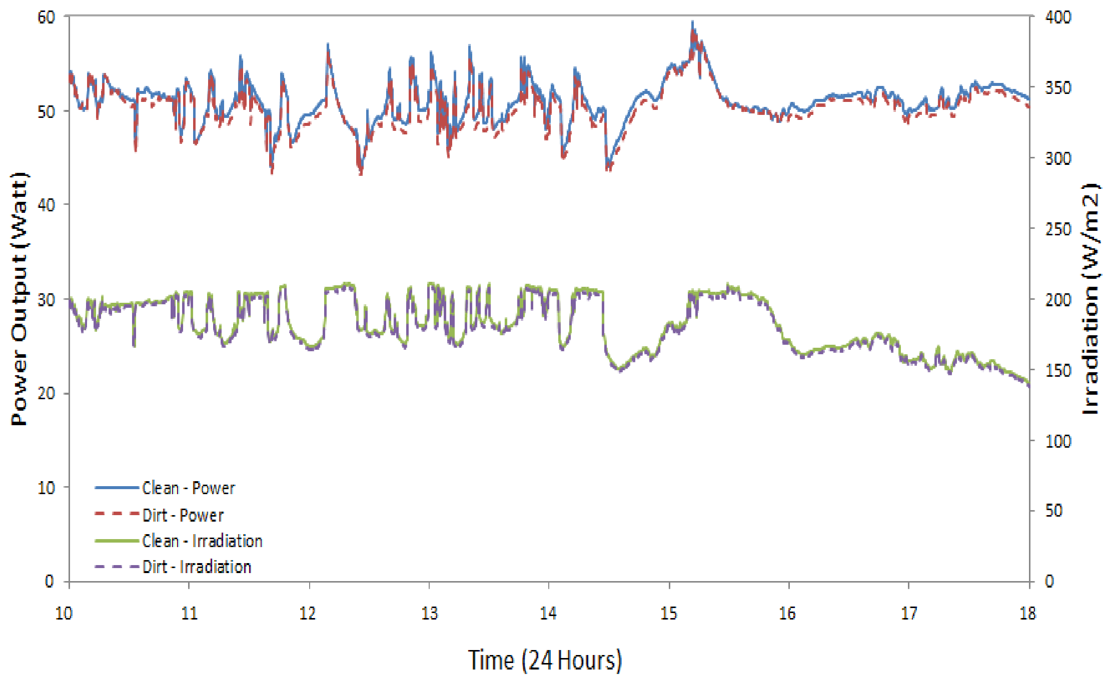
Variation of output and irradiation with time on daily test 3



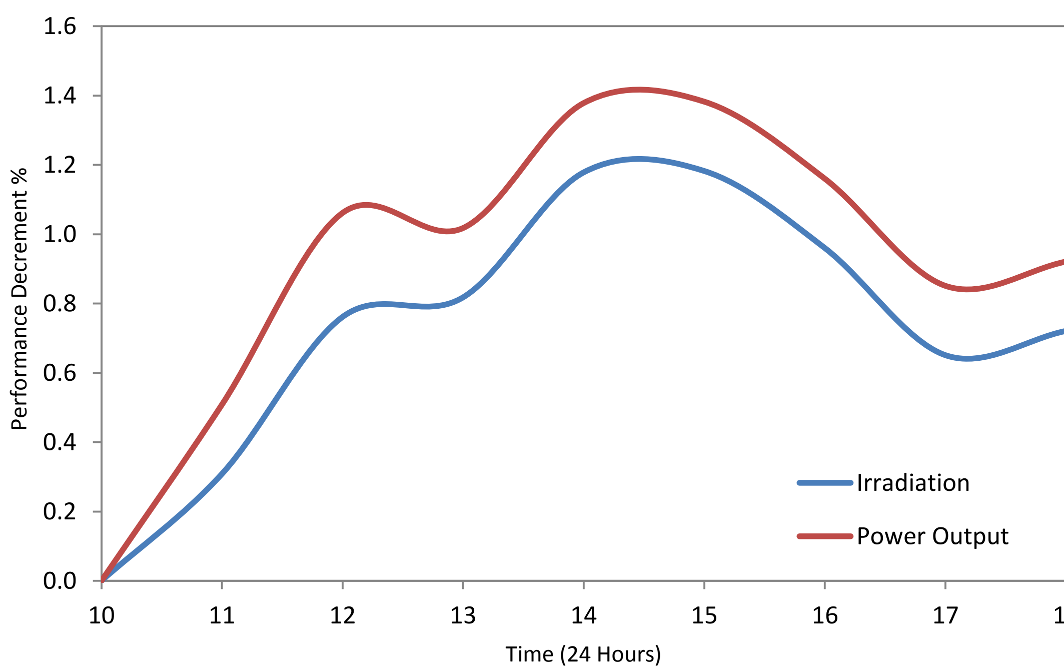
Graph of performance drop with time on daily test 3

Appendix D : Weekly Test

Weekly Test 2

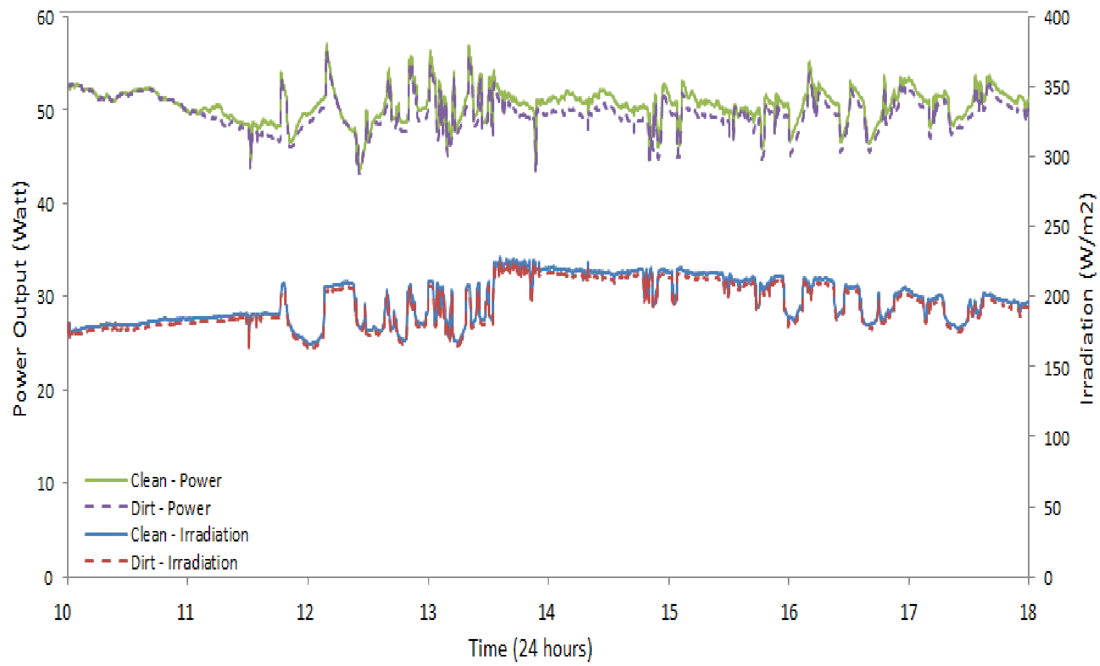


Variation of power output and irradiation with time for weekly test 2

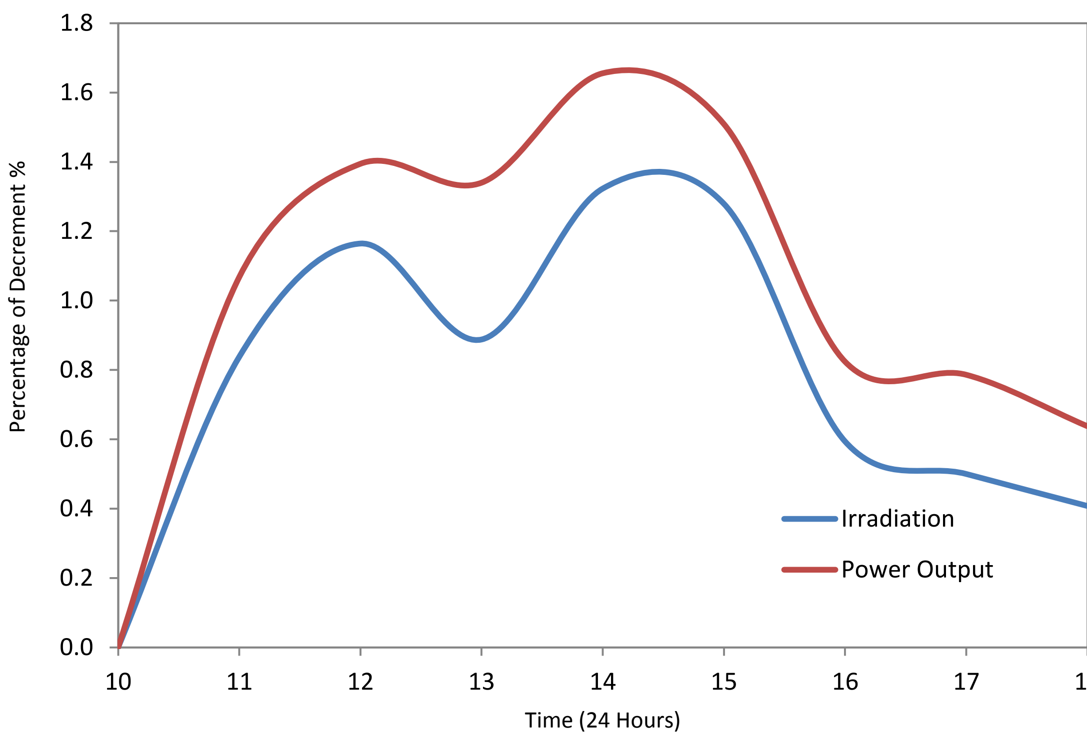


Variation of performance drop with time for weekly test 2

Weekly Test 3



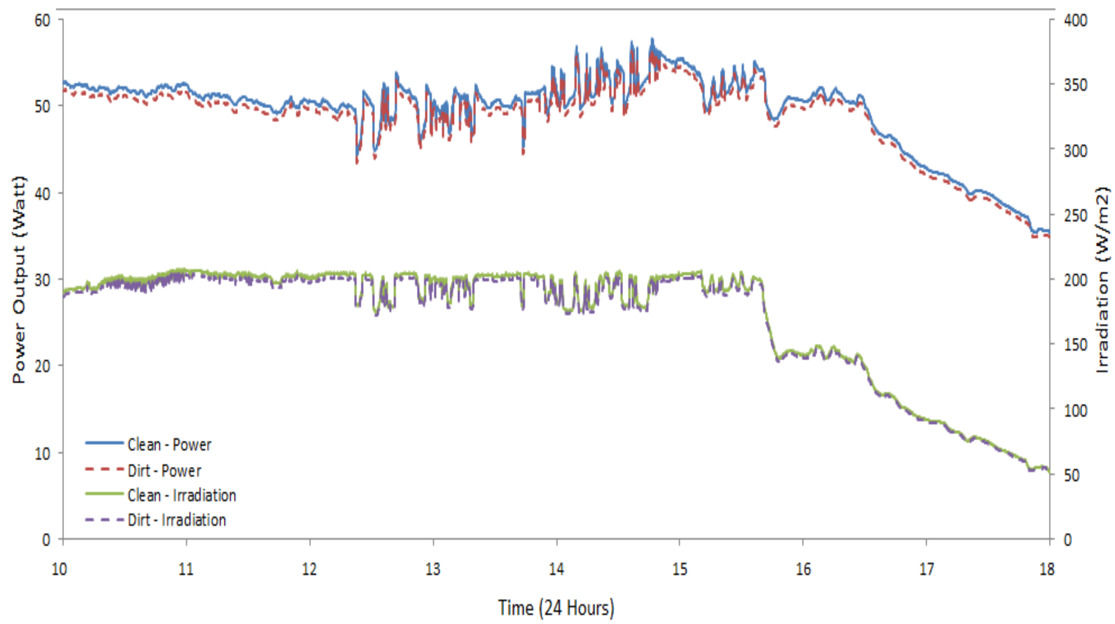
Variation of power output and irradiation with time for weekly test 3



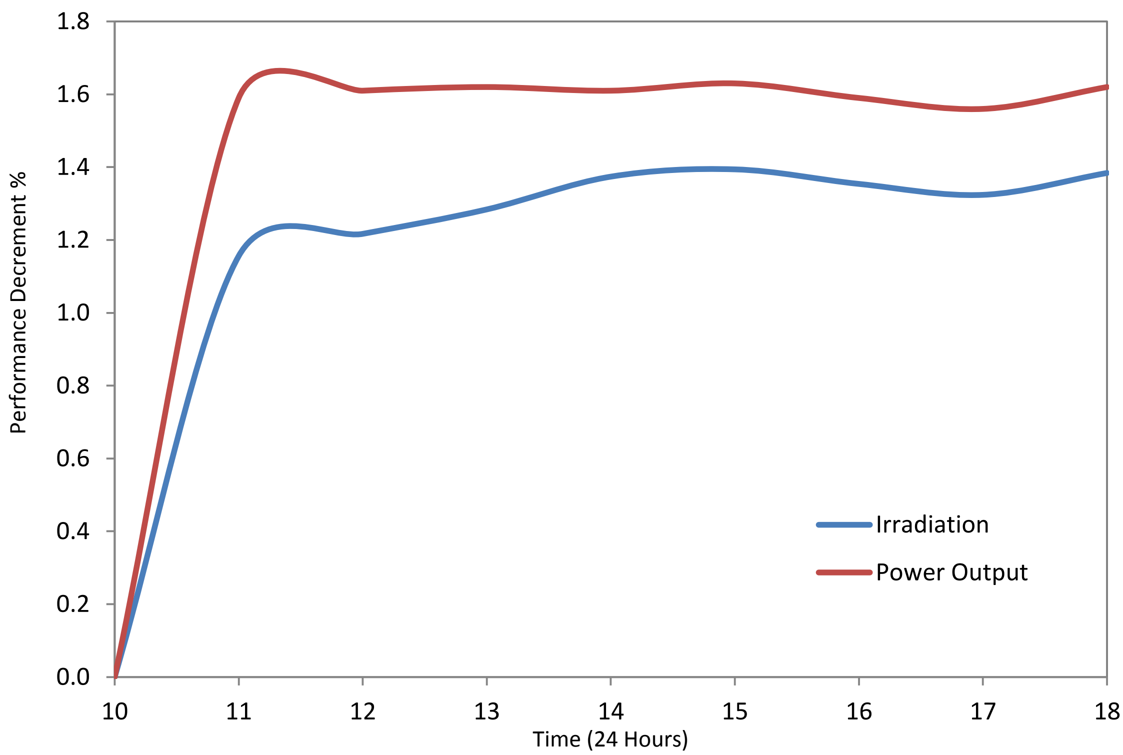
Variation of performance drop with time for weekly test 3

Appendix E : Monthly Test

Monthly Test 2

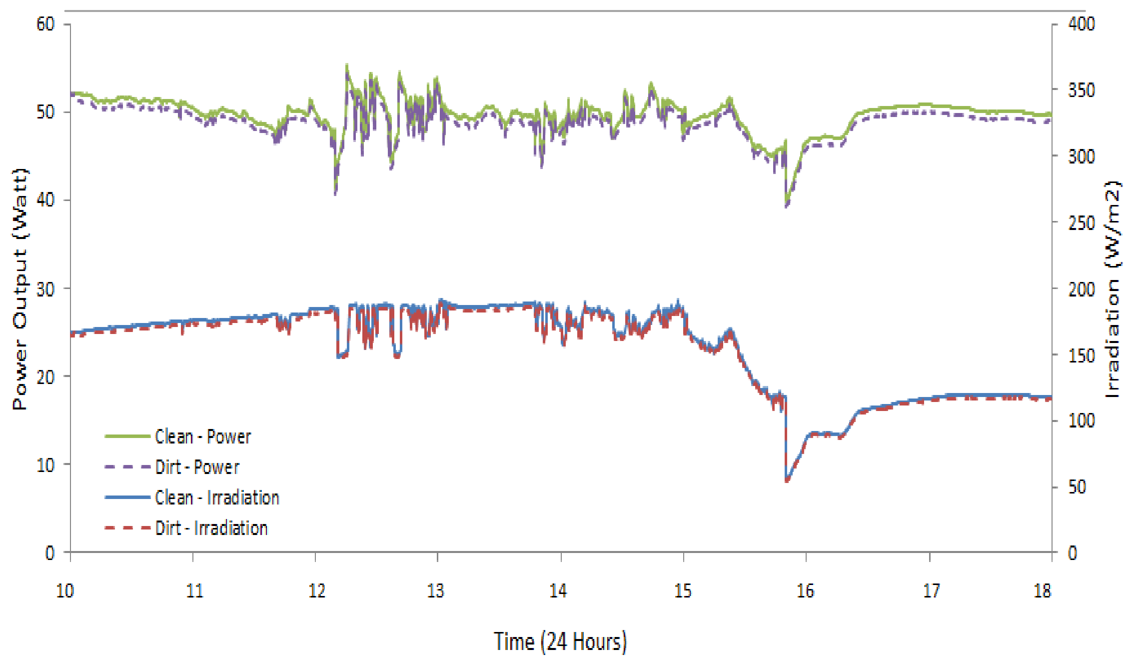


Variation of power output and irradiation with time for monthly test 2

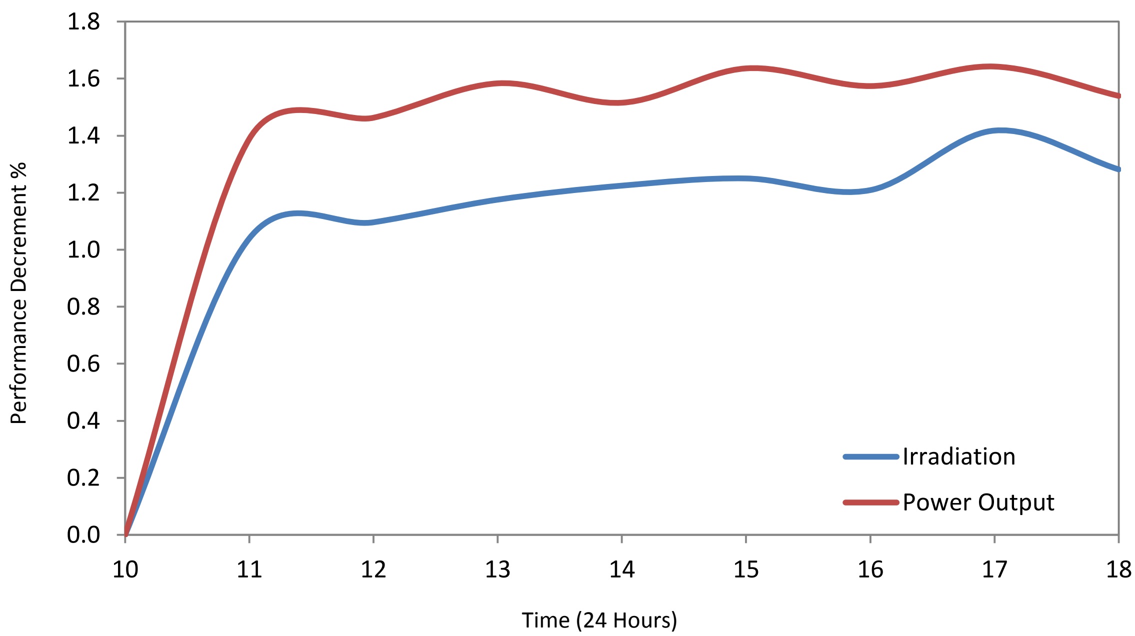


Variation of performance drop with time for monthly test 2

Monthly Test 3



Variation of power output and Irradiation with time for monthly test 3



Variation of performance drop with time for monthly Test 3

Appendix F : Calculation on Maintenance of Cleaning Time

Revenue Gain

Residental	Industrial
Nominal Power Rating 4kW **Malaysia receives sunlight** 5 hours/day **Production for 1 day** 4kW × 5 hrs.= 20 kWh/day **Production per month** 20 kWh/day ×30 day/month (600 kWh/month) **Current Feed-in Tariff (2014)** RM 1.20 per kWh **Monthly revenue** RM 1.20/kWh × 600kWh (RM 720)	**Normal Power Rating** 30 MW **Malaysia receive sunlight** 5 hours/day **Production for 1 day** 30MW × 5 hrs.= 100 MWh/day **Production per month** 100 MWh/day ×30 day/month (3000 MWh/month) **Current Feed-in Tariff (2014)** RM 0.85 per kWh **Monthly revenue** RM 0.85/kWh × 3000 MWh (RM 2.55 Million)

Cost Incurred due to Performance Drop

Residental	Industrial
Performance drop of 1 month 1.57% **Cost of performance drop** RM 720 × 1.57/100 **RM 11.30**	**Performance drop of 1 month** 1.57% **Cost of performance drop** RM 2.55 M × 1.57/100 **RM 40,035.00**

Cost Incurred due to Hiring Workers and Buying Cleaning Agent

Fact: Malaysia receives 4000-5000 Wh per m^2 per day taking 4500 Wh per m^2 / day.

4,500 Wh per m^2 × 365 days/ year = 1.642 Mwh/m^2 (http://www.met.gov.my/)

Residental	Industrial
Energy required for Solar PV panel 20 kw/day × 365 Days/Year × 24 hrs/day = 175,200 kWh **Required Area of Solar Panel** 175,200 kWh/1.642 Mwh/m^2 **106.70 m^2**	**Energy required for Solar PV panel** 100 Mw/day × 365 days/year × 24 hrs/ day = 876,000 Mwh **Required Area of Solar Panels** 876,000 MWh/1.642 Mwh/m^2 **533,495.74 m^2**

Cleaner Service Rate:

RM 5.00/ hours (Malaysia Payscale Human Capital)

Estimate completed cleaning time for 1 panel approximately takes 5 minutes

1 panel size (780 mm × 550 mm) = 0.429m^2

5 minutes/ 0.429 m^2 = 11.66 mins/m^2 = 0.194 hr/m^2

Standard service of cleaner for 1 hour = RM 5.00

0.194 hr/m^2 × RM 5.00 /1 hour = RM 0.97 per m^2

By including the cost of cleaning agent RM 0.03 per panel (estimate)

Total cost required RM 1 per m^2 panel

Residental	Industrial
Area of solar PV panel 106.70 m^2 **Lost per year** RM 1.00 /m^2 × 106.70 m^2 (RM 106.70) RM 106.70 × 12 cleaning time/year **RM 1280.4** Amount of money losts per year due to maintenance of cleaning time	**Area of solar PV panel** 533,495.74 m^2 **Lost per year** RM 1.00/m^2 × 533,495.74 m^2 (RM 533,495.74) RM 533,495.74× 12 cleaning time/year **RM 6,401,948.88** Amount of money losts per year due to maintenance of cleaning time