An-Najah National University

Faculty of Engineering & Information Technology

Mechanical Engineering Department

Graduation Project (2)

The Recent Cleaning Techniques in Solar PV: A Review

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كلمة شكر

أشكر الله العلي القدير الذي أنعم عليَّ بنعمة العقل والدين. القائل في محكم التنزيل **"وَفَوْقَ كُلِّ ذِي عِلْمٍ عَلِيمٌ "سورة يوسف آية 76** ... صدق الله العظيم.
وقال رسول الله (ﷺ) **"من صنع إليكم معروفاً فكافئوه, فإن لم تجدوا ما تكافئونه به فادعوا له حتى تروا أنكم كافأتموه"** ... رواه أبو داوود

أهدي تخرجي إلى والدي العزيز الله يحفظه الى من حصد الأشواك عن دربي ليمهد طريق العلم لي والى التي جعل الله الجنة تحت أقدامها الى التي غمرتني بفيض حنانها الى التي احترقت لكي تنير لي دربي الى التي جاعت لأشبع وسهرت لأنام وتعبت لأرتاح وبكت لأضحك وسقتني من نبع رقتها وصدقها الى التي ربتني صغيرا ونصحتني كبيرا قرة عيني وفؤادي أمي الغالية أطال الله في عمرها وجعلها خيمة فوق رؤسنا الى من قاسموني أفراحي واحزاني اخوتي الى من جمعني بهم منبر العلم والصداقة زملائي الذين أكّن لهم أسمى عبارات المحبة.

لابد لنا ونحن نخطو خطواتنا الأخيرة في الحياة الجامعية من وقفة نعود إلى أعوام قضيناها في رحاب الجامعة مع أساتذتنا الكرام الذين قدموا لنا الكثير باذلين بذلك جهودا كبيرة في بناء جيل الغد لتبعث الأمة من جديد... وقبل أن نمضي تقدم أسمى آيات الشكر والامتنان والتقدير والمحبة إلى الذين حملوا أقدس رسالة في الحياة... إلى الذين مهدوا لنا طريق العلم والمعرفة إلى جميع أساتذتنا الأفاضل.

ثم أشكر أولئك الأخيار الذين مدوا لي يدَ المساعدة، خلال هذه الفترة، وفي مقدمتهم الدكتور المشرف على مشروع التخرج الدكتورعادل الجعيدي الذي لم يدَّخر جهداً في مساعدتي, كما هي عادته مع كل طلبة العلم.

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1. Abstract:

Solar energy is one of the most important sources of renewable energy, clean and environmentally friendly. The amount of energy produced by photovoltaic cells at 46.9% worldwide depends mainly on the amount of radiation that reaches solar cells. There are many factors that depend on the amount of radiation that reaches the solar cells for better performance. The environment is one of these factors, which plays a key role in performance. Solar panels are exposed to dust, which adversely affects performance efficiency. For example, in Saudi Arabia, a decrease of 32% was reported due to the accumulation of dust on the PV system. To solve this problem, there was a solution to get rid of accumulated dust on the photovoltaic panels using cleaning. Manual cleaning takes a long time and may have a negative impact on photoelectric performance. Therefore, many techniques used for dust removal and cleaning have been studied by knowing the advantages, disadvantages, working mechanism and efficiency of each of these techniques. The mechanical method was chosen and applied in practice. Through the work of a robot mechanical cleaning the PV every 24 hours to get rid of accumulated dust. After the implementation of this project we found that this method is one of the best ways to be used in the cleaning of PV in Palestine.

Table (1): List of Abbreviation.

Abbreviation	Meaning
PV	Photovoltaic
CSP	Concentrating Solar Power
MENA	Middle East and North Africa
RHX	Rectangular Heat Exchanger
PC-Si	Polycrystalline Silicon
A-Si	Amorphous Silicon
MC-Si	Mono-Crystalline Silicon

2. Introduction:

Solar energy is the most abundant renewable energy source and the technology to harness the solar energy includes the use of Photovoltaic systems and solar thermal systems **[1].** PV systems are playing a crucial role in meeting our future energy demand and it has been considered as an environmental benign and eco-friendly source of electrical power **[1].** Energy supply might be one of the main financial issues that our society is currently facing **[2].** Renewable energies appear to be a meaningful solution because several of the conventional energy resources exploited at present are being depleted **[3].** In particular, the MENA region (Middle East and North Africa), where non-renewable energy resources are unsustainable, is suffering a significant increase in energy consumption **[4].** This issue has been intensively addressed in recent years, with the implementation of several renewable energy programs **[5–7],** some of them specifically focused on solar energy **[8,9].** Solar energy is leading the renewable energy scene because it is both free and endless **[10,11].**

A PV system (protected with cover glass) for harvesting solar energy is usually installed in sun-drenched desert areas, outdoors and roof tops of urban and rural areas, where dry weather and winds sweep dust and deposit onto the surface of the solar panel **[1].** Hence, the glass covering system is commonly used to protect the solar cells from moisture, rain, traffic dust, heat, ultraviolet radiation, bird excrement and corrosive acidic rain in real outdoor environments **[1].** During the course of time, the glass surfaces of the solar panels become contaminated with the dust particles from transport vehicles, industrial chimney wastes and pollution **[1].** Such dust particles deposited over the cover glass of the panels hinder the incident light photons to reach the working part of the solar cell and consequently reduces the output electrical power **[1].** Also, CSP plants are often located in arid and semi-arid locations with harsh weather conditions that can involve severe dust deposition, reducing the reflectance and consequently the CSP plant power production **[12,13].** Moreover, dust can completely terminate the system operation in some cases **[14].** The absorption and scattering of radiation are the two mechanisms responsible for the reflectance reduction caused by dust and soil deposition on the reflectors **[13].**

The effect of dust deposition on average transmittance on rainless days that there was 8% decrease in transmittance at a tilting angle of 45° after 30 days of exposure **[14].** The effect of dust accumulation on the average permeability with respect to the tilt angle **[15].** The average permeability with the inclination angle and loss of permeability is higher for the weekly cleaning cycle than for the daily cleaning cycle **[1].** From the effect of dust deposition there was a 50% reduction in permeability **[16].** The effect of fine particles has a greater influence than coarse particles on the performance of solar energy, for the same type of dust **[17].** So, the accumulation of dust particles on the solar panels has negative significance on the transmittance of incoming light radiation and overall cell efficiency; thus, making PV as an unattractive energy source for harnessing solar radiation **[1].**

There are characteristics of dust settling on PV systems by two fundamental factors that affect each other, namely dust property and the local environment **[1].** The local environment comprises site-specific factors influenced by the nature of prevailing (human) activities, built environment characteristics (surface finishes, orientation and height of installation), environmental features (vegetation type) and weather conditions **[1].** Soiling of solar panels can occur as a result of dust and dirt accumulation **[1].** Soil deposits depend on site environment, climatic conditions, and solar field orientation in combination with wind directions **[18–20].** Consequently, the impact of soiling must be included as a major role when performing the potential exposure site study **[21].** Another effect of soiling on CSP plants is the higher probability of solar materials degradation due to the interaction with airborne particles **[22–26].** In many cases, the dirt is washed off the panel surface by rainfall or water sprinkling; however, dirt like bird droppings may stay even after heavy rains **[1].** The most critical part of a module is the lower edges. Usually, large-scale solar power plants are being installed in desert and dry areas **[1].** But dust accumulation is an unavoidable problem in these areas as it forms as layers and decreases the solar power conversion of 40% and these plants may lose nearly 30% energy output within short period **[6].** Hence, it is highly essential to maintain the solar cell panels with frequent cleaning with the installation of automatic cleaning systems like solar wash or, manually which may increase the cost of PV and its maintenance **[1].**

In considering the issues presented above, it is strongly insisted that cleaning of cover glass of the solar panels is mandatory and obligatory part of the maintenance **[1].** There have been several methods suggested for maintaining the solar panel efficiency, which includes manual cleaning, natural source of cleaning and by mechanical mode of cleaning via wipers and robotic arm **[1].** And manual cleaning represents a high peril for cleaning persons who works at a height of (12 – 30) feet from the ground level and a tire some work in the case of large area surfaces **[1].**

Natural sources of cleaning include wind and rain storms will effectively clean the solar panel cover glasses **[1].** Cleaning with wind is reported as a non- feasible technique, as there is a need of high wind velocity to clear off the dust particles and the velocity will vary according to different geographical locations and seasonal conditions **[1].** Cleaning with rain is whispered as a method of effective cleaning, but actually it is a method of cleaning with low efficiency and if the pollution of the local environment is high, leaves debris over the surface of the solar panel after rainfall **[1].**

Soiling of PV panels, which is the process by which airborne particles deposit and accumulate on solar panels, impacts the performance of the PV energy system **[28].** Production of electricity from clean energy sources is a critical mitigation strategy to overcome the global warming challenge **[29].** The countries located in the Sunbelt region and the Middle East have higher solar energy potentials than many other regions in the world, however, with a significant disadvantage of soiling, which necessitates frequent and costly cleaning of solar panels **[29].** The main challenge of implementing solar energy systems in these hot dry climates is dust and soiling on the surface of the panels and collectors in addition to high-temperature levels **[29].** Both reduce the efficiency of solar PV panels significantly and hence increase the cost of electricity produced,

making solar energy systems not competitive enough with abundant fossil fuel resources such as natural gas **[29].**

The presence of dust raises some negative impacts in the application of a PV module deployed in the field **[30].** Performance of the PV module generally quantified by its power, current, and voltage tends to decrease as dust in the atmosphere impinges onto its glass cover surface **[30].** Dust is made up of small solid particles in the atmosphere with a diameter less than 500 µm **[31]** which generated by human, animals and natural activities **[32].** The reason is that dust particles reduce and even block the sunlight to reach PV cells **[33].** Performance degradation of PV modules due to dust can be recovered through a cleaning activity **[34].** It can be performed manually and automatically for small and large system respectively **[30].**

Natural event such as rain can also relieve the dust effect, but the cleanliness level of the PV modules is dependent on the rainfall **[30].** Although the power loss due to dust is temporary but its value is relatively significant especially in areas with low precipitation such as desert areas **[35–43].** In year 2011 Kaldellis and Fragos **[45]** in a study in Greece investigated the impact of dust on efficiency of several modules featuring identical technical specifications **[30].** They found that the addition of dust of 0.4 (mg/cm^2) from a clean condition, there was a decrease in PV efficiency by 1.5% **[30].** A similar trend was also demonstrated by another study conducted by Jiang et al. **[46]** looking at the effect of dust on the efficiency of three types of PV cell technology, namely polycrystalline silicon (pc-Si), amorphous silicon (a-Si), and mono-crystalline silicon (mc-Si) **[30].** It was reported that as the amount of dust escalated from 0 to 22(g/m^2), efficiency of these cells dropped up to 26% **[30].**

Also investigated the effects of five types of dust on the performance of PV module **[30].** Results revealed that ash particles accounted for the highest voltage reduction followed by red soil, calcium carbonate, silica, and sand. In addition to the grain size distribution, the literature shows that the optical properties of dust are also driven by other morphology factors including shape and surface texture **[47, 48].**

In a study reported that the influence of dust from Kuwait was more significant on PV modules working on a wide spectral such as thin film technologies **[30].** This effect was indicated by a reduction in the spectral transmittance values of dust at lower wavelengths (300–570 µm) **[30].** In the present study, they studied the effect of dust collected from Perth, Australia, Babuin and Indonesia. The study investigated the performance of three technologies of PV, namely PC-Si, A-Si, and MC-Si. These two regions are geographically different so it would be expected that the dust have different morphology properties that lead to different performance degradation of PV modules **[30].**

Table (2): The Type of PV Technologies.

The Type of PV Technologies			
	Polycrystalline Silicon	**Amorphous Silicon**	**Mono-Crystalline Silicon**
Author	Maehlum, M. A	Maehlum, M. A	Maehlum, M. A
Years	2015	2015	2015
Definition	Unlike monocrystalline-based solar panels, polycrystalline solar panels don't require the Czochralski process is a method of crystal growth used to obtain single crystals of semiconductors, metals, salts and synthetic gemstones **[49].**	Amorphous silicon (a-Si or a-Si:H) solar cells belong to the category of silicon thin-film, where one or several layers of photovoltaic material are deposited onto a substrate **[49].**	Monocrystalline solar cells are made out of silicon ingots, which are cylindrical in shape **[49].**
Mechanism	Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers **[49].**	The silicon material is not structured or crystalized on a molecular level **[48].** Are stacked several amorphous solar cells on top of each other, which increases their performance and makes them more space-efficient **[49].**	Four sides are cut out of the cylindrical ingots to make silicon wafers, which is what gives monocrystalline solar panels their characteristic look **[49].**
Efficiency	The efficiency of polycrystalline-based solar panels is typically 13-16% **[49].**	Amorphous thin-film solar cells have lower efficiency rates (typically around 6-8%) **[49].**	The efficiency rates of monocrystalline solar panels are typically 15-20% **[49].**
Advantages	The process used to make polycrystalline silicon is simpler and cost less. The amount of waste silicon is	Requires much less silicon **[49].** Amorphous silicon is a direct-bandgap material, and	Monocrystalline solar panels have the highest efficiency rates since they are made out of the

	less compared to monocrystalline [49]. Polycrystalline solar panels tend to have slightly lower heat tolerance than monocrystalline solar panels [49].	therefore only require about 1% of the silicon that would`ve been used to produce a crystalline-silicon based solar cell [49]. The substrates can be made out of inexpensive materials such as glass, stainless steel and plastic [49]. Can be made flexible and lightweight [49].	highest-grade silicon [49]. The efficiency rates of monocrystalline solar panels are typically 15-20% [49]. Monocrystalline solar panels live the longest [49]. Most solar panel manufacturers put a 25-year warranty on their monocrystalline solar panels [49].
Disadvantages	The efficiency of polycrystalline-based solar panels is typically 13-16% [49]. Because of lower silicon purity, polycrystalline solar panels aren't quite as efficient as monocrystalline solar panels [49]. You generally need to cover a larger surface to output the same electrical power as you would with a solar panel made of monocrystalline silicon [49].	Amorphous thin-film solar cells have lower efficiency rates [49]. Thin-film solar panels tend to degrade faster and not last as long as mono- and polycrystalline solar panels [49]. You would have to cover a larger surface with amorphous silicon solar panels than crystalline-based solar panels for an equal output of electrical power [49].	Monocrystalline solar panels are the most expensive [49]. From a financial standpoint, a solar panel that is made of polycrystalline silicon (and in some cases thin-film) can be a better choice for some homeowners [49]. If the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down [49].

Cooling PV System:

The PV cell directly converts the incident solar irradiance to electricity. The most efficient, sustainable, and eco-friendly systems are the PV modules which convert small part of the solar irradiance to electricity. The remaining part of the solar irradiation then converts into heat, which increases the temperature of the cells and reduces the performance of the PV module **[50].**

One of the main obstacles that face the operation of photovoltaic panels (PV) is overheating due to excessive solar radiation and high ambient temperatures. Overheating reduces the efficiency of the panels dramatically **[51].** The ideal P–V characteristics of a solar cell for a temperature variation between 0 C^o and 75 C^o **[52].**

The two types of cooling techniques (passive cooling and active cooling) to remove the heat transfer and enhance the performance of the PV cells **[53].**

Air cooling:

1. **Heat sink:**

Heat sink is one of the cooling ways which uses a high thermal conductivity metal to remove the heat from the photovoltaic cell **[54].**

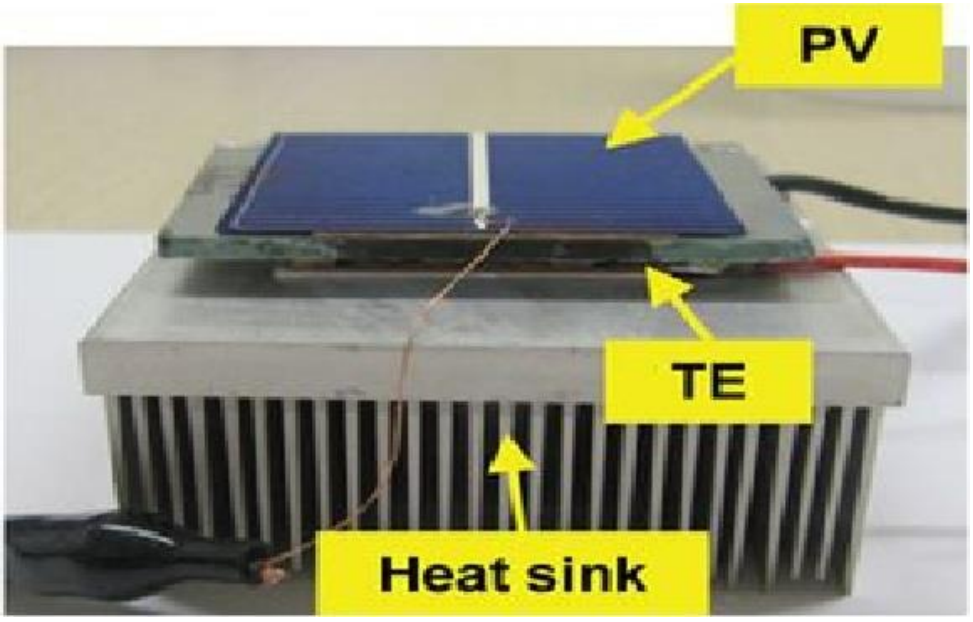


Figure 1: Hybrid PV/TE system with heat sink.

2. **Air channels:**

Investigated the performance of the PV cells with active cooling by using air channels connected to the back of the PV panel **[55].** The electrical efficiency was decreased when the cells operating temperature increased for both cooling and non-cooling cases, but for the cooling case the electrical efficiency was higher **[53].**

Figure 2: Hybrid solar Photovoltaic/Thermal system cooled by forced air circulation.

Water cooling:

1. **Water spray:**

Both sides of the PV panel were cooled at the same time, the results were measured for three different cases of cooling: front side cooling, rear side cooling and both sides together and compared with non-cooling case **[56].** The water spray cooling has achieved a suitable effect on the PV panel performance and the best case was the simultaneous front and back sides cooling PV panel **[57].**

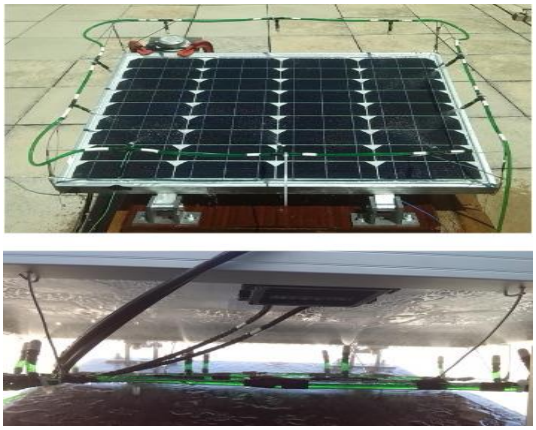


Figure 3: Hybrid solar Photovoltaic/Thermal PV/T system cooled by water spraying.

2. Heat exchanger:

The cooling mechanism contain of heat exchanger and seven pipes of water attached to the back of the PV panel **[53].** The electrical efficiency of the PV panel was improved more in the case of 0.3 L/s water flow rate **[58].** Compared the performance of the PV panel with rectangular heat exchanger cooling (RHX) attached to the back with the PV panel without cooling **[53].** The maximum cell efficiency for the rectangular heat exchanger cooling was 13.07%, while for uncooled PV cells was 7.82% **[53].**

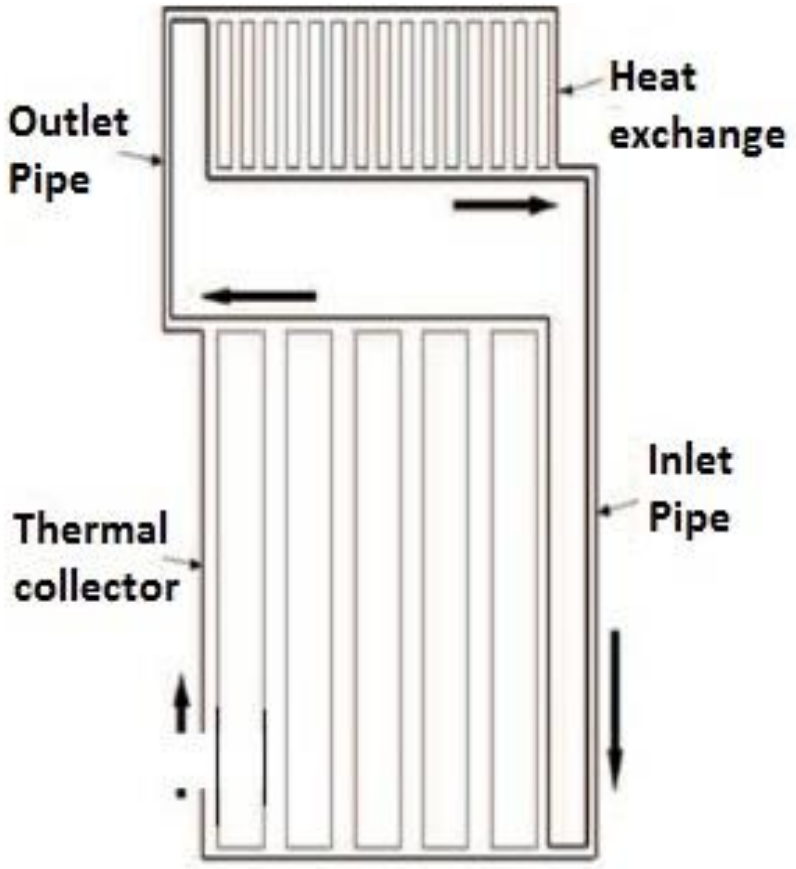


Figure 4: Hybrid solar Photovoltaic/Thermal system cooled by Heat exchanger**.**

Table (3): PV- Cleaning methods.

Methods for Self-Cleaning of Solar Photovoltaic Panels			
	Methods		
	Mechanical	**Electrostatic**	**Coating**
Definition	The mechanical methods remove the dust by brushing, blowing, vibrating and ultrasonic driving. ` The brushing methods clean the solar cell with something like the broom or brush that were driven by the machine was designed just like windscreen-wiper **[59].**	Electrostatic method expels the dust especially lunar dust outside from electric curtain through electrostatics' standing and traveling wave **[60]**, contains two types: standing-wave electric curtain, traveling-wave electric curtain **[60].**	The coating method is used to protect the substrates from the environment. The method has changed the surface properties of the substrates, such as adhesion, wettability, corrosion resistance, and wear resistance. Coatings can be applied on the substrates by using gases, solids or liquids depend on the end-user techniques **[60].**
Mechanism	A mechanical method has four techniques to expel the dust which are a robotic method, air-blowing method, water-blowing method and ultrasonic vibration method **[60].**	If there is a high potential on the surface of the solar panels, the charged and uncharged dust will be attracted to the panels because of the electrostatic forces. Then, the dust particles will be charged by the solar panels finally, so they have the same electric charge and the electrostatic forces between them are repulsion. At last, the dust particles will float away from the solar panels **[61].**	When the solar panels have a layer of pellucid nanofilms capable of self-cleaning, it cleans itself automatically. The Self-Cleaning Nano-Films method mainly use two strategies for cleaning the solar panel, namely superhydrophilic Material or Super – Hydrophobic Materials **[62].**
Advantages	Machines able to clean up the solar panel within a short period of time and have high dust removal efficiencies **[60].**	The power consumption of this system is virtually zero. This technology is expected to increase the effective efficiency of mega solar power plants constructed in deserts at low latitudes **[63].**	Relatively cheap, and the coating is easy to apply on solar panel surfaces **[64]**, no power consumption, nor do they create scratches **[60].**

Disadvantages	Cleaning method is not that efficient because of the sticky nature and small size of the dust particle. It is also seen that difficult and harsh working condition of the solar power plant makes the maintenance of these machines difficult. Also, the solar power plant is present over a very large area which makes this cleaning method expensive and inefficient **[62].**	This strategy cannot be used in the PV system, because of the effecting of the rain on the earth, also needs electrical power to operate **[61].**	In superhydrophobic coatings, surface durability cannot withstand to outdoor exposure for more than few months **[60].**

Table (4): Cleaned PV panels in a middle of a desert.

Natural and Manual Cleaning Comparison Between Performance of Man-Made and Naturally Cleaned PV Panels in Gulf States.	
Country	**Drop of PV Performance**
Bahrain	That the density of the accumulated dust, ranging from 5 to 12 g/m^2, causes drop of PV power to about 40% of its maximum available **[65].**
Qatar	The investigation of solar PV performance under Doha weather using a Poly-crystalline panel was found to decrease by around 30% due to dust exposure of 5 months which lead to conclude that cleaning frequencies of PV panels is important **[66].**
United Arab Emirates (UAE)	That PV panels losses their power from 40 W (cleaned) to 13 W (during dust storm), i.e. Loss of nearly 68% **[65].**
Saudi Arabia	Compared to an identical PV system tilted at 24.68° and is cleaned daily **[65].**
Kuwait	It was also reported a reduction in PV power output by 17% due to sand accumulation, on panels after a period of 6 days and also found that the influence of dust on PV performance was higher in spring and summer (20% in 6 months) than in autumn and winter **[65].**
Oman	The results show that the ash pollutant is the most effecting dust particle on the PV module voltage as compared to the other used dust pollutants. The highest reduction in PV voltage (25%) is recorded when the ash pollutant is used **[65].**

This figure explains the causes of dust accumulation:

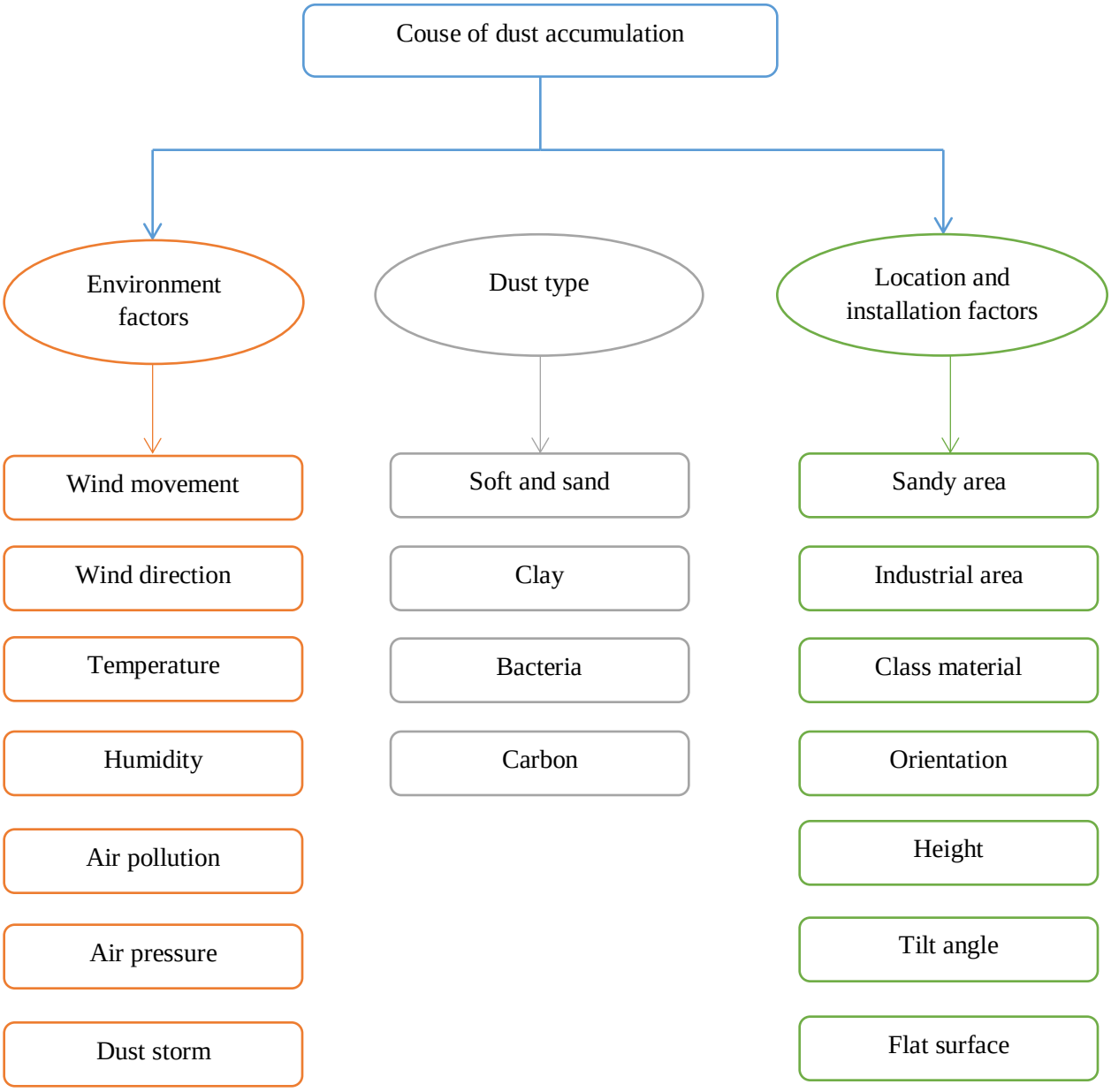


Figure 5: Causes of dust accumulation.

This figure explains the Factors which affect the efficiency of PV module:

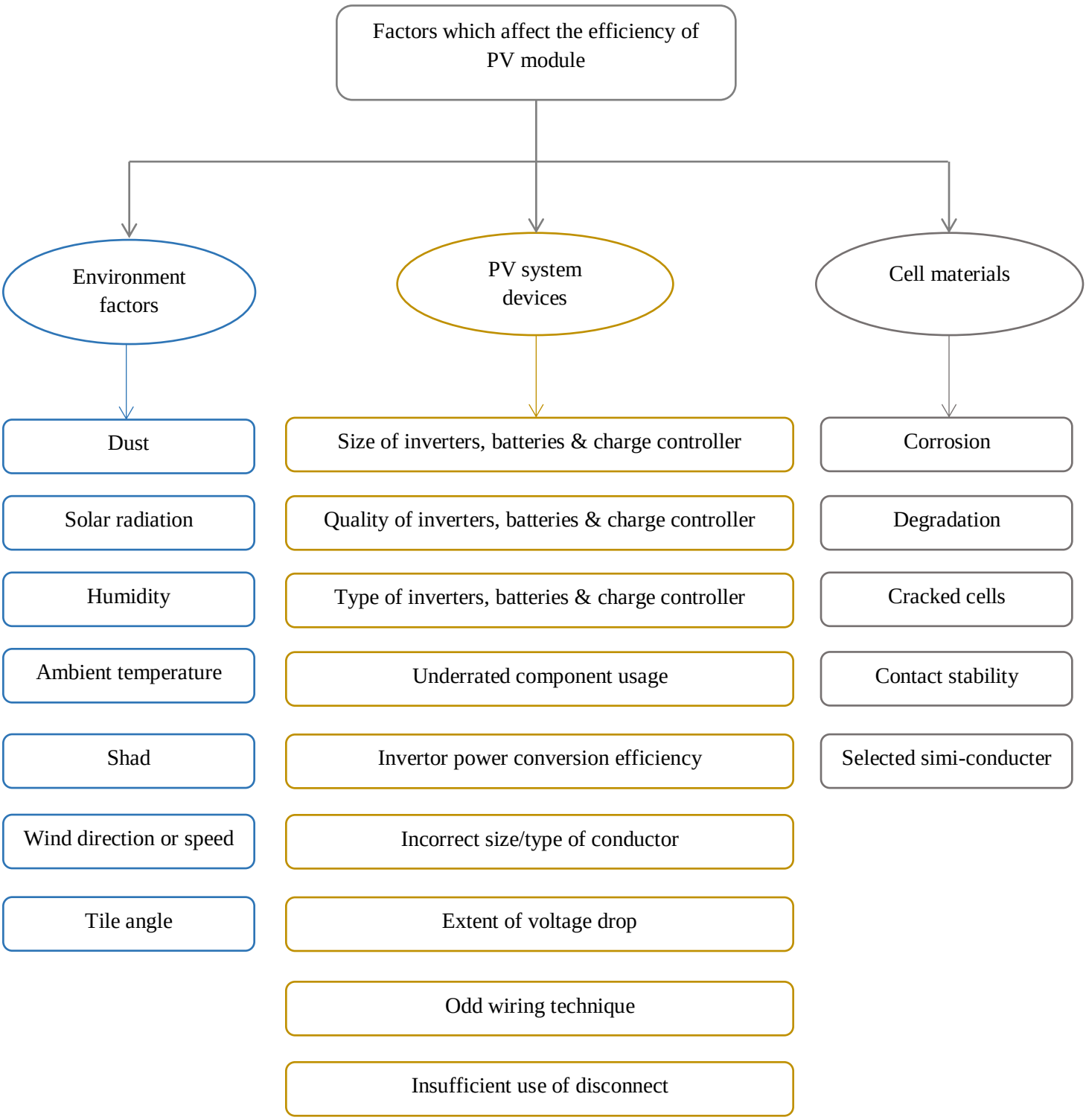


Figure 6: Factors which affect the efficiency of PV module.

Various methods of PV glass cleaning are given in **Figure .1.** As below:

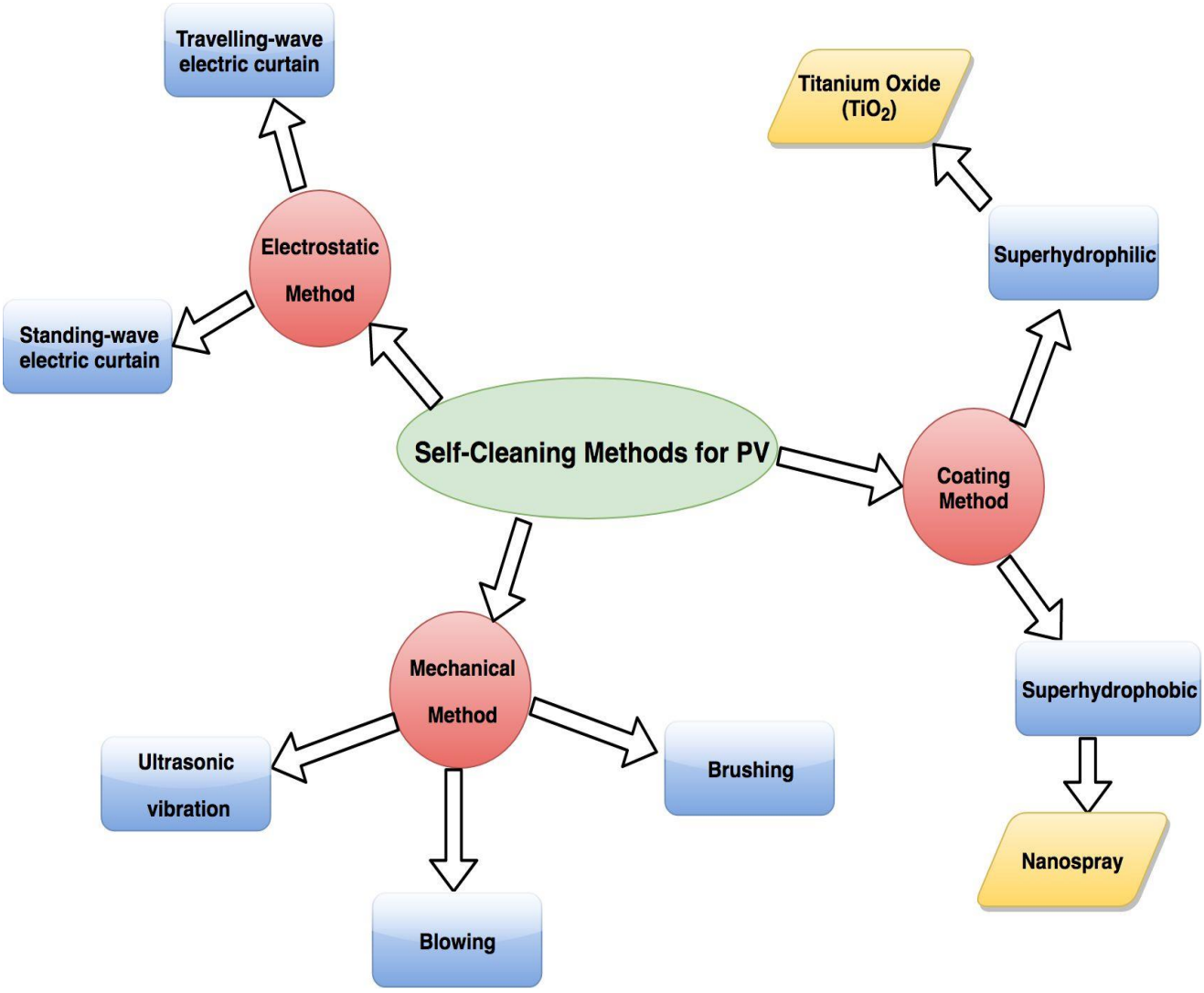


Figure 7: Self-cleaning methods for PV

3. Methodology:

The climate of the state of Palestine is characterized by a long, hot, dry summers and short, cool, wet winters **[67].** Only the southern part of the Jordan Valley has a different transitional climate between dry steppe and the extreme desert conditions of the Dead Sea region **[67].** Climate within Palestine is affected by distance from the Mediterranean, latitudinal position, the climate of the West Bank, especially in the south, is influenced by the vast nearby Negev and Arabian deserts especially during spring and early summer **[67].** Desert storms move through with hot winds full of sand and dust (locally known as Khamaseen winds) which increases the pollution of solar panels and reduces their ability to produce electricity **[67].**

Relative Humidity: The relative humidity has an influence on PV panels, especially the very low humidity experienced during the Khamaseen. Hot winds may cause damage to the PV panels. The relative humidity in the state of Palestine varies between (50-70%) **[67].**

Dust is still a major challenge for the solar industry at the operation and maintenance level, as dust cumulation on panels can significantly decrease the power production of those panels.

The modern mechanical method uses to clean the solar cell which was discussed how they worked, and the cleaning equipment which used in solar PV referred to cleaning operations. There is a mechanical method to clean dust which are fat method, air blowing method, ultrasonic vibrations, and this project we work on the robot method for cleaning the solar pv cell due to the ability to clean up the solar panel within short period of time and have high dust removal efficiencies.

The robot cleaning method cleans the solar PV cells using special brush which rotates at high speed without damaging the cell. Dust is then cleaned from the surface of cell and it doesn't return to its surface. The robot uses mechanical and electrical equipment from the wheels and brush, it has 4 motors and many kinds of sensors to control its movement. It has a specific algorithm for making decisions, and the size of robot is (35*40) cm.

Human cleaning of these panels is cumbersome, costly, time consuming, and human cleaning may not reach areas that the robot can reach safely. The robot working on the project is made to clean these panels without any interference from human effort and it provides safe access to areas which can't be cleaned; and if it is damaged, although this happens very rarely because the parts were chosen carefully and are suitable for environmental conditions, their maintenance, jaw and installation are easy.

In this project, the project is designed to be a 29 ° angle oblique PV panels, such as the angle used in Palestine and suitable for climatic conditions throughout the season. After running the project, the engines can't move the robot up, due to the heavy weight of the robot. After using these engines, we could not replace them with larger engines. Therefore, the angle of the PV panels was reduced to 7 degrees. This is the largest angle the robot can move in without any obstacles.

4. Literature Review:

Table (5): Literature review (till 2019) scientific review with pre-defined methodology.

Author	Country	Type of Method	Duration	Dust
Al-Housani.M, et al. (2019).	Qatar **[68].**	Mechanical cleaning **[68].**	6 months **[68].**	Gravel/sandy **[68].**
Cai, Shibo, et al. (2019).	China and Brazil **[69].**	Robotic cleaning **[69].**	3 months **[69].**	Dust with diameter 40 µm **[69].**
Conceição, Ricardo, et al. (2019).	Portugal **[70].**	Cleaning of PV with using movable tilt angle frames **[70].**	8 months **[70].**	Accumulated dust and debris **[70].**
Sorndach.T, et al. (2018).	Thailand **[71].**	Robotic cleaning **[71].**	No Duration mentioned.	Dust layer of 4 gram per square **[71].**
Manju.B, et al. (2018).	India **[72].**	The Automatic Cleaning System **[72].**	30 days **[72].**	Pollen and dust **[72].**
Brian Parrott, et al. (2018).	Saudi Arabia Thuwal **[73].**	Robotic dry-cleaning of solar panels by using a silicone rubber brush **[73].**	37 days **[73].**	Accumulated dust and sand **[73].**
AIDARA, Mohamed Cherif, et al. (2017).	Senegal, Dakar University **[74].**	The Robotic cleaning system using brush **[74].**	31 days **[74].**	Dust layers containing salt or similar chemical deposits **[74].**
Masood Ul Hassan, et al. (2017).	Saudi Arabia **[75].**	Robotic cleaner **[75].**	7 days **[75].**	Layer of dirt and Sand **[75].**
Moharram, K. A., et al. (2013).	Egypt **[76].**	Mechanical Cleaning **[76].**	45 days **[76].**	Sand particles (Particle Size Analyzer of 40 µm ± 10 µm) **[76].**

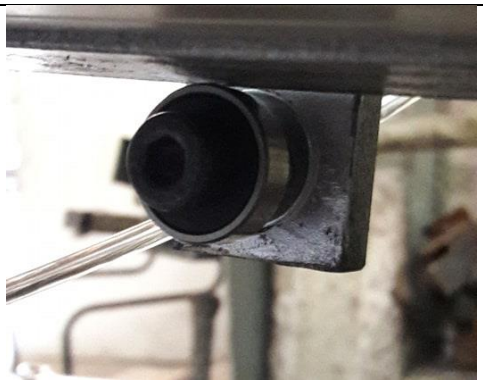
5. Design Analysis:

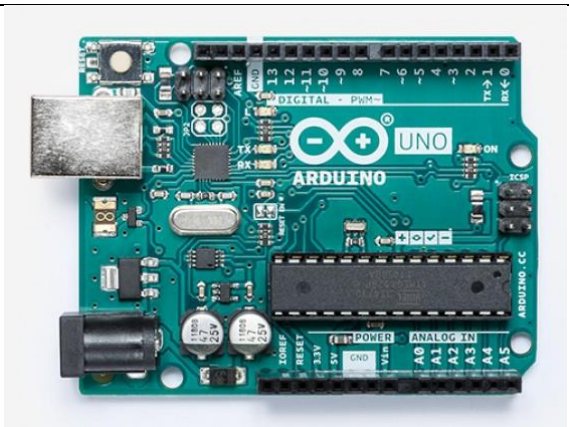
A mechanical robot designed with a brush to clean the cells of the solar panels. The brush is installed on a frame made of iron. The brush moves counter clockwise by motor, running at 300 rpm. The principle of the robot's action: This robot is moved by pressing an electric switch, where the robot moves down by engines installed on rough wheels moving on the iron frame at 15 rpm. At the end of the solar panel, the robot movement is reversed by the micro switch. Where the robot is programmed into an electric panel so that it moves every 24 hours back and forth. But the robot can be run at any other time. In this table will be detailed all the electrical and mechanical components used in the practical project:

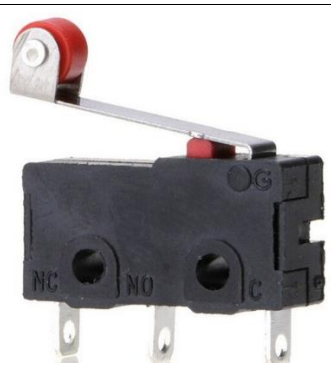
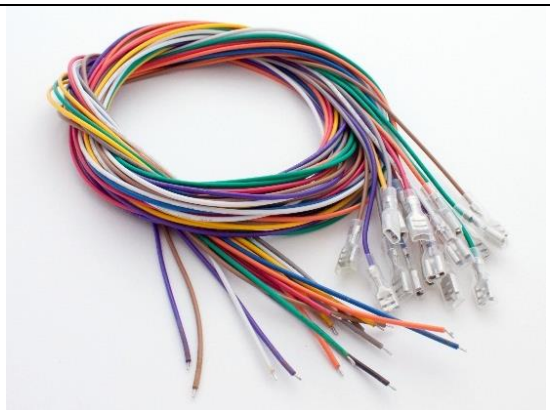
Table (6): The electrical and mechanical components used in the practical project.

Piece	**Function**	**Price (₪)**	**The shape**
Solar panel	Photovoltaic solar panels absorb sunlight as a source of energy to generate electricity.	300 ₪	
Motors (Number 5)	**Brush motor:** Moves the brush counterclockwise at 300 rpm. **Motors on wheels:** convert the electrical energy into mechanical energy, and the motors move the wheels at 15 rpm.	450 ₪	

Wheels (Number 4)	Works to move the robot down and upward by motors.	50 ₪	
Brush	The brush is installed on the robot so that it cleans the PV panels, through engine rotation, at 300 rpm.	80 ₪	
Nuts and bolts	To install the motors on the wheels as well as installing pillow block bearing on the frame.	30 ₪	
Washer	A washer is a thin plate used to distribute the load of a threaded fastener, such as a bolt or nut.	10 ₪	

Pillow Block Bearing (Number 2)	Installs the brush, prevents any vibration during brush rotation, and contains a bearing to help the brush rotate.	50 ₪	
Bearing (Number 4)	It is used to install the robot on the frame while in motion.	27 ₪	
Paints (Number 2)	Paint the frame in silver. Paint the robot with nickel color.	36 ₪	

Rod (Number 2)	To install the two ends of the robot	35 ₪	
Simplified Iron Bar (Number 2)	To install and collect the frame	40 ₪	
Arduino and Drivers	**Arduino:** electronic development board consisting of an open source electronic circuit with a microcontroller on one board that is programmed. It is programmed to move the robot every 24 hours back and forth. **Drivers:** In electronics, a driver is a circuit or a component used to control another circuit .Used to regulate the flow of current through the circuit or to control other factors such as some devices in the circuit, where 3 drivers were used, one driver per two wheels, and a driver to brush, in order to control the speed of the wheels and brush.	35 ₪	

Micro Switch (Number 2)	Reverses the motion of the motor connected to the wheels when reaching the end of the PV panel.	16 ₪	
Wires	Connect all motors with a piece of Arduino.	11 ₪	
Power supply (Number 2)	Supply of electric motors.	30 ₪	
Total		1200 ₪	

After applying the project in practice, we encountered a problem. The project is designed to be angle tilted PV panels 29 degrees. This angle between the tilt angle of paintings in summer and winter. After running the project, the engines can't move the robot up, due to the heavy weight of the robot. After using these engines, we could not replace them with larger engines. Therefore, the angle of the PV panels was reduced to 7 degrees. This is the largest angle the robot can move in without any obstacles.

Figure 8: Mechanical robot for cleaning PV panels.

6. Conclusion and Recommendations:

Several factors have been studied that contribute significantly to the accumulation of dust on the surfaces of solar cell panels, including: rain, humidity and wind (which have a significant impact on the accumulation of dust in desert areas). The amount of energy produced by optical cells is reduced by the accumulation of dust, and the amount of energy produced (5-80) %. The angle of installation of the solar panels affected the performance of the cells. The loss of energy from the horizontal panels (8-22%) and the loss of the panels at an angle of 45 ° (1 - 8) %. Therefore, the solar cells should be installed on the panels to minimize losses caused by dust accumulation. Three main methods of cleaning accumulated dust were studied: mechanical, plating, static electricity, each with certain advantages. The mechanical method was the most efficient method, where paint was the least expensive way, and did not consume static electricity in its application. The most effective method was chosen (Mechanical). A mechanical robot was used to clean the PV every 24 hours. It increases the efficiency of solar cells and increases the resulting energy. The robot eliminates more than 90% of the accumulated dust. Therefore, cleaning the PV mechanically is one of the most efficient methods that can be applied in Palestine. And also, everywhere contains solar power plants.

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