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Automated Water Cooling and Solar Tracking for Efficiency Improvement of PV Systems: A Systematic Review

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ABSTRACT

This article presented previous efforts for overcoming low photovoltaic (PV) solar panel electrical efficiencies resulted from excess heat problem reached in hot climates. Utilizing water cooling, temperature-controlled water cooling and solar tracking solar systems are discussed in this paper. Water is a perfect medium can be used for absorbing excess heat due to its high thermal capacity, availability and low cost. In addition to, utilizing control systems for water cooling systems based on Arduino unit and microcontroller chip which can be interfaced with Bluetooth, WIFI, and Internet of Things (IOT) enhances saving time and effort in large PV solar plants and PV performance. Solar tracking systems, depend on light-dependent resistors (LDRs) which are resistors operated by incident light, or ultraviolet (UV) sensors which are detectors based on incident ultraviolet radiation sensing enhances PV performance. Solar tracking systems enhances PV electrical efficiency compared to fixed PV panels. PV efficiencies of latest studies were presented and compared. Utilizing water cooling systems enhances PV electrical efficiency up to 30%, using an ON-OFF temperature-controlled water-cooling systems increased overall efficiency up to 51.4% and can reduce consumption of water up to 29.28%. In addition to, using two solar tracking systems enhances PV solar panel efficiency up to 65%. The increase in PV installation faces challenges includes millions of solar waste tons that harms environment and human health. However, it can be eliminated utilizing recycling technologies. Artificial intelligence (AI), machine learning techniques would enhance PV performance analyzing and data collection.

1. Introduction

Photovoltaic (PV) solar panels, which convert solar radiation into electricity, have evolved significantly since their first discovery by Edmond Becquerel in 1839 and the first functional panel developed by Charles Fritts in 1882. Today, PV systems offer a promising renewable energy solution to address the growing global energy demand and reduce dependence on fossil fuels.

Solar power plants are classified into two PV systems: photovoltaic solar panels which employ the photovoltaic effect for converting radiation from the sun into electrical energy [1]-[3]. and thermal solar collectors which convert solar radiation directly into heat [4], [5]. In thermal solar systems solar radiation is concentrated for increasing heat sink temperature and producing steam at high temperature. High temperature steam is being used for generating electricity in steam power plant. USA and Spain have been using this type of solar power plants [6], [7]. Photovoltaic solar systems excited free electrons in PV embedded semiconductor by solar photons of incident solar light. PV solar panels are used in several scales such as integrating with building walls, in open spaces, rooftops, vehicles and many panels arranged in arrays. Appeal of PV panels mass public led to increasing their demands and widely installing in addition to reducing customs duties systems cost [8], [9].

Similar to other semiconductor devices, solar panels may suffer variations in temperature. A rise in temperature will decrease the energy of semiconductor bandgap [9]. The effect of temperature on the bandgap of semiconductors like silicon, carbon, gallium arsenide, and gallium phosphide has been reported previously [10]. According to their findings, the bandgap at a given temperature $E_g(T)$, can be explained as follows:

$$E_g(T) = E_g(0) - S(h_w)[\coth\left(\frac{h_w}{2KT}\right) - 1] \quad (1)$$

Where $E_g(0)$ represents the bandgap at zero kelvin equaled -273 ◦C, S is the constant value of a dimensionless coupling and h_w is the averaged energy value of phonon. Additionally, they discovered that the temperature dependency on the bandgaps can be estimated with a linear relationship to the following formula at high temperatures, where the inequality $KT \gg (hw)$ holds.

$$E_g(T) = -2KS(T) \quad (2)$$

To date, there has been no research conducted on the relationship between temperature and bandgaps even for simple metal oxides, which are commonly employed as photo catalysts [11]. Moreover, not enough has been said about the parameters used to determine the bandgap which results in narrowing phenomenon at high temperatures [11].

Many environmental conditions, including the spectrum of incident solar radiation [12], [13], relative humidity, the ambient temperature [12], [14], wind speed [14], [15], the accumulation of dust [16], [17], and partial shade [18], [19], have a major impact on the small efficiency level of PV cells [20]. Due to the increasing temperature of the PV panels during summer, they suffer from low efficiency and worse performance [20]-[22]. Their electrical efficiency is usually low between 15% to 22% [23], [24]. High PV surface temperature led to low PV electrical efficiencies and bad performance. It was found that increasing PV surface temperature reduces the maximum power output of the PV panel [25], He found that maximum power output from a PV panel with 25◦C surface temperature is more than maximum power output from a PV panel with 50◦C surface temperature. Increasing the PV panel temperature leads to PV material destruction due to the overheating [26]. Solar PV power plants are considered the solution to the good energy lack in sunny and hot climatic countries, but this leads to increasing the PV panel temperature [27]. This increasing in temperature is coming from the conversion of a part of the solar radiation into heat [28]-[30]. Scientists used different cooling systems such as water-based, in which the excess heat is extracted from the PV by the water, air based, phase change material (PCM), thermoelectric cooling systems and solar tracking systems to overcome PV low efficiency problem.

This paper reviews the previous studies on the PV water cooling systems, the PV solar tracking systems, and the developed temperature control systems for improving the PV electrical efficiency. The main purpose of this study is to give guidelines to the scholars during the development of their methods how to decrease the effect of PV high surface temperature, control PV temperature and enhance the performance measure of the PV system as well as providing a summary of previous studies focused on water cooling, controlled water-cooling techniques and solar tracking PV solar systems. This paper contains a more detailed information about the challenges face utilizing PV solar panels, water cooling and solar tracking techniques. The rest of this paper is organized as follows. Section 2 studies the effect of water PV cooling systems on the performance and the efficiency of the PV system. In Section 3, the water flow control systems are reviewed and compared with illustrating the use of Arduino platform with various temperature sensors using ON-OFF and Proportional Integrated Derivated (PID) control types. In addition, their effect on the PV surface temperature, performance and efficiency are presented. Section 4 investigates the effect of the PV solar tracking on the electrical efficiency using light dependent resistor sensors (LDRs) and UV ultraviolet sensors. Finally, Section 5 summarizes the main important points in this paper and give some recommendations for the researchers for future works.

2. Methodology

The previous relevant studies which focused on water cooled, temperature-controlled water cooled, and solar tracking PV solar system as illustrated in Fig. 1. Firstly, are identified then it is selected as well as having its evaluation, analyzing and synthesizing as a procedure for establishing the systematic review.

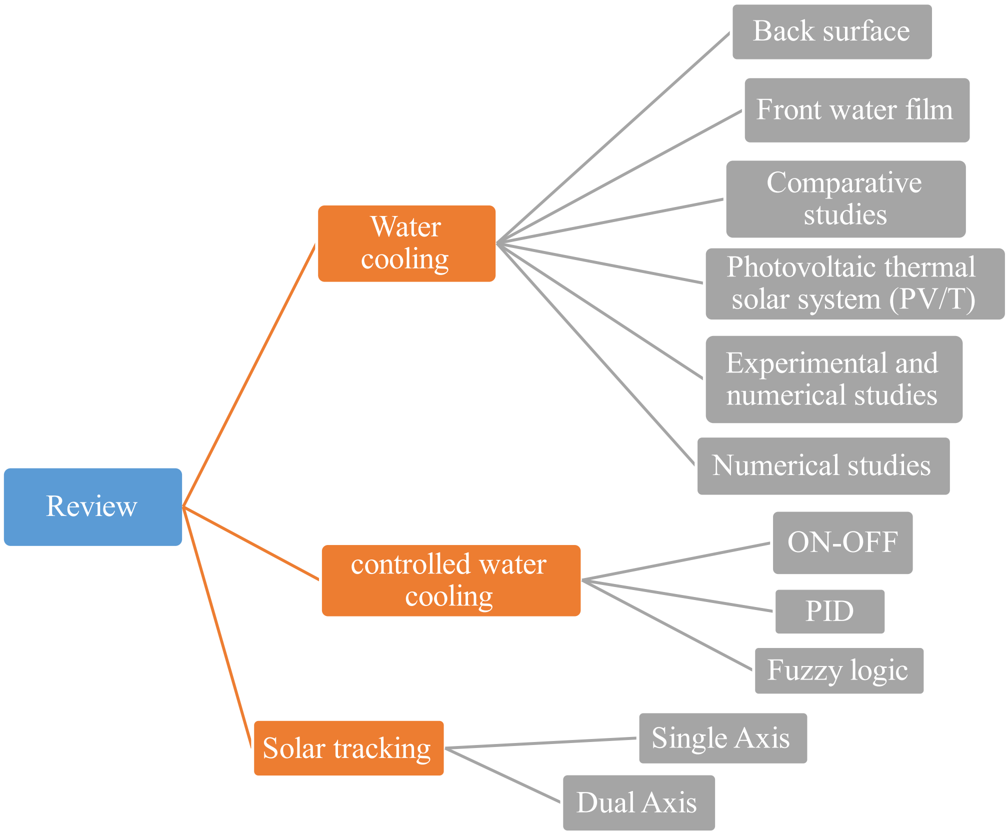

Fig. 1. Flowcharts of presented review study

The systematic review steps is presented as follows:

- The question of research is the guide of the review process. Establishment, challenges and performance improvement of utilizing water cooled, controlled water cooled, and single and dual solar tracking system is the target of question.
- The need of a systematic research is required for the identification of related studies. Water cooling techniques as well as utilizing control systems such as arduino and utilizing solar tracking systems within several databases such as ScienseDirect (Fig. 2, Fig. 3 and Fig. 4), Google scholar and IEEE Xplor.

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- Related studies were selected after scanning according to considering some factors such as how it related to the question of research, the date of publication, system establishment, output gains.
- Scanning and selection the related studies begins with the title followed by the abstract then the assessments of the full text
- Data and information were extracted from the selected studies according to mechanism established, type of study, temperature reduction and output power and electrical efficiency increase.
- Selected studies results and findings were analyzed and compared

Discussion of the findings of the review were guided by the search question. Future recommendation and utilizing photovoltaics limitations were discussed. A conclusion of the review results was illustrated as a final part of the review.

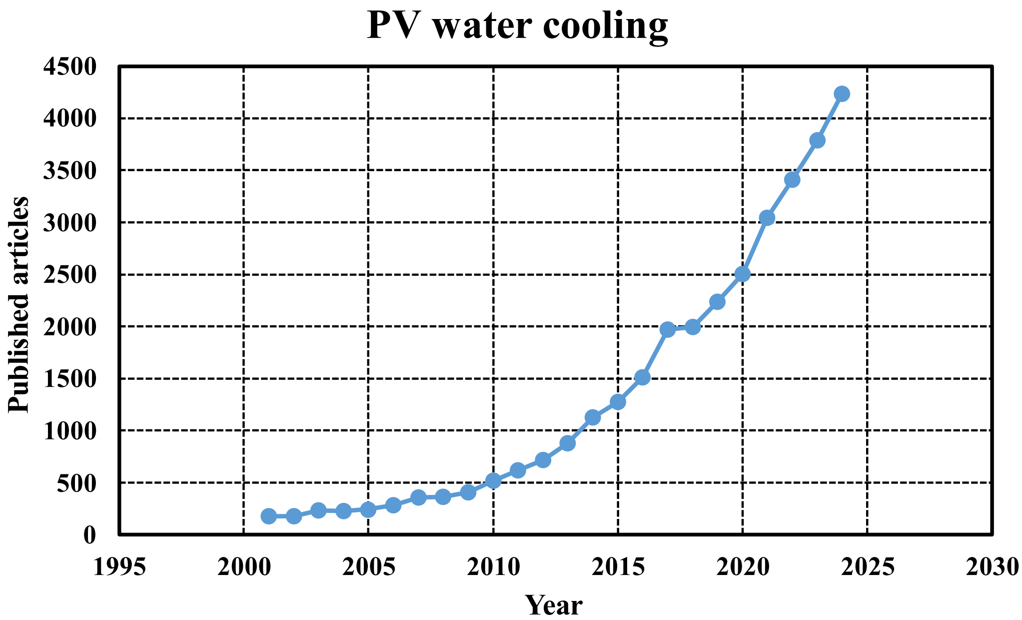

Fig. 2. ScienseDirect search results of "PV water cooling systems"

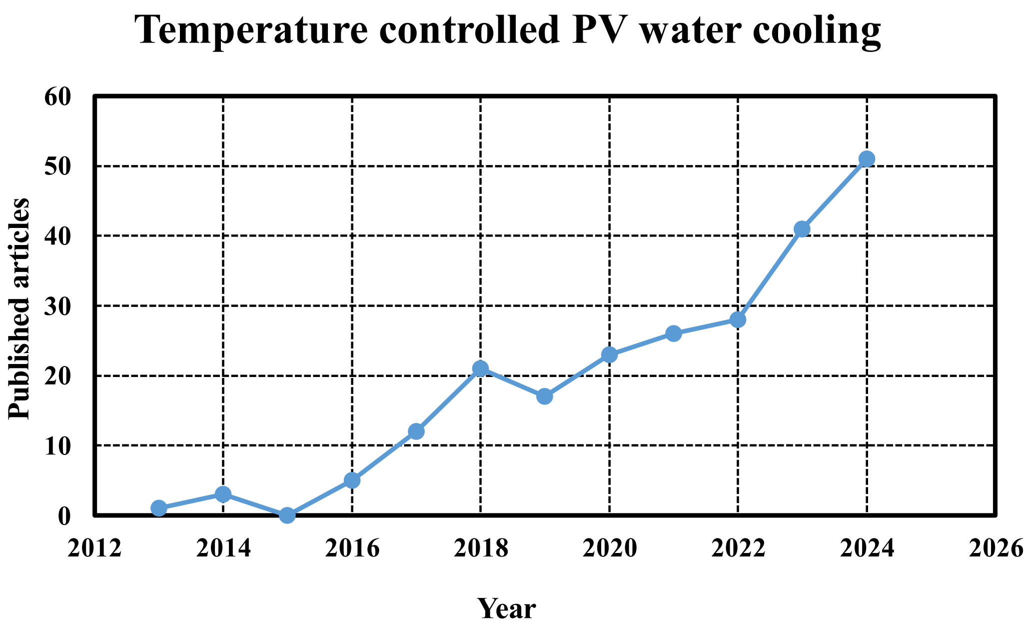

Fig. 3. ScienseDirect search results of "Temperature controlled PV water cooling system"

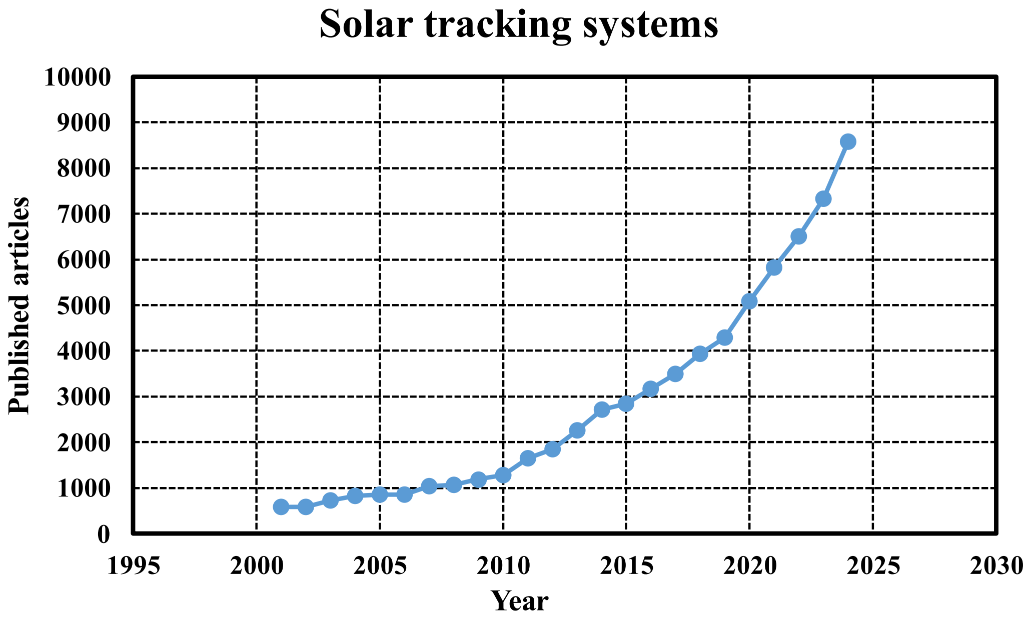

Fig. 4. ScienseDirect search results of "PV solar tracking systems"

3. Effect of Water-Cooling Systems on PV Performance

Scientists found that PV cooling system is a good solution for overcoming increasing temperature [31], [32]. Water cooling system is recommended to be a good solution for eliminating the increase in the temperature of PV solar panels [32]. Piotrowski et al. [25] found that using water cooling system for PV panels increase the efficiency with 30% compared to uncooled units and also reduces the rate of PV unit degradation by 3%. El Nozahy et al. [33] made a study in which a PV surface temperature variation was occurred during day of a water cooled and non-cooled PV panel. They managed to reach 20◦C reduction of PV front face surface temperature at 2.00 PM time of day by using the PV water cooling system compared to non-cooled PV system. Ahmed et al. [34] investigated the effect of temperature, incident solar irradiance, velocity of wind, deposition of dust and cooling water on 50W PV performance in region of Rajshahi located in Bangladesh. They established their study using Data logger, multi-meter and a laptop. Using a 0.0045 m3/min cooling water circulation enhances efficiency of exergy, efficiency of energy production and PV power output by 37.5%, 12% and 20.47% at 730 up to 780 W/m2 incident solar irradiation

3.1. Back Surface Water Cooling Systems

Shalaby et al. [35] studied the effect of using PV back surface water cooling system on the electric power generation and efficiency. Their study revealed that the power generation was increased by 14.1% compared uncooled case. Furthermore, the electrical efficiency value was increased by 2.4 which equaled a 13.79% increase percentage compared with the uncooled case. Masalha et al. [36] focused on decreasing PV back surface temperature using a porous media with different porosities and different water mass flowrates for increasing PV power output and improving PV electrical efficiency. A schematic diagram of PV solar system used is illustrated in Fig. 5. They established their study using three techniques. The first one was a comparison between three cases. Case 1 was with a porous media with 0.35 porosity, case 2 was with water cooling without any porous media and case 3 was without cooling. The second technique was a comparison between three cases. Case 1 was a PV cooling with a porous media with 0.35 porosity, case 4 was with a porous media with 0.4 porosity and case 5 was with a porous media with 0.48 porosity. The third technique was also a comparison between three cases. Case 6 was using a porous media 0.35 porosity with 1 l/min water mass flowrate, case 7 was using a porous media 0.35 porosity with 2 l/min water mass flowrate and case 8 was using a porous media 0.35 porosity with 3 l/min water mass flowrate. Study results showed a 35.7% maximum reduction in PV back surface temperature, a 9.4% increasing in PV power output in case of 0.35 porosity and 3 L/min water mass flowrate.

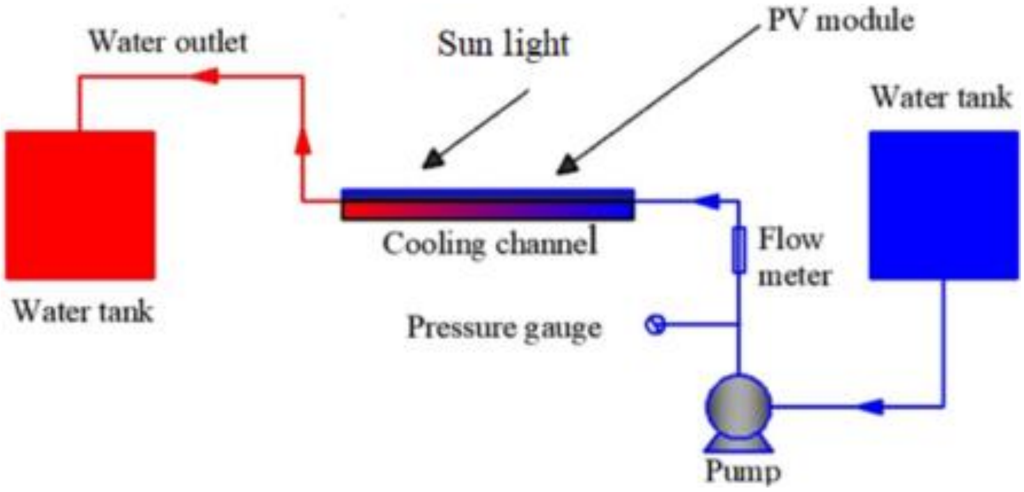

Fig. 5. Showed the PV solar system used schematic [36]

3.2. Front Water Film Cooling

Schiro et al. [37] used water for cooling PV units and they chose water so as to not change the PV unit's module structure as illustrated in Fig. 6. They used water film cooling type to reduce the PV panel temperature.

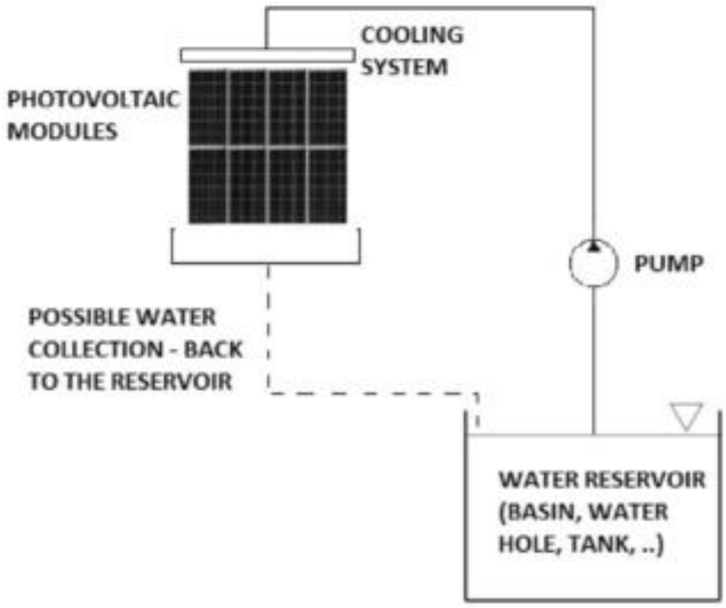

Fig. 6. PV cooling system scheme [37]

Yi Mah et al. [38] found that the performance of a PV which is a crystalline silicon was reduced due to the increasing PV surface temperature. In their study, the film cooling type was used for cooling the PV panel surface. The results presented that the water film cooling type method increases the PV efficiency, but it also decreases the uniformed distribution of temperature on the panel surface, so they used an optimum amount of water flowrate of 6 L/m to improve the temperature distribution and this amount produced an increasing of 32 watts of PV power output which means that the output power was increased by 15%. The optimum amount of cooling water flowrate is the optimum amount that can absorbs highest amount of excess thermal energy from PV solar panel material without any influence on the incident solar radiation flux on PV solar panel surface and the overall cost. Lucas et al. [39] used a compression chiller for providing the PV cooling water. They used the back cooling system with the aid of solar chimney and the front water cooling with the aid of a water film on the front face of the PV. Their results showed an average amount of cooling equal to 15◦C with 10% increasing in the PV electrical efficiency.

3.3. Comparative Studies

Hadipour et al. [26] focused on methods of enhancing PV electrical efficiency and improving PV performance. In addition to studying ways to reduce PV destruction using a water-cooling system which is a pulsed technique by pumping sprayed cooling water in a non-continuous period of time. They made a comparison study between four cases. Firstly, was without any cooling PV system. Secondly, it was a steady spray PV water cooling system. Thirdly, it was a spray water cooling system which is pulsed with duty cycle equal 1. The pulse period is sum of periods of ON and OFF states, the width of pulse is the ON state period of time and the pulse duty cycle is the ratio of pulse width to the pulse period [40]. Fourthly, it was a spray water cooling which is pulsed with duty cycle equals 0.2. Study results showed that using spray water PV cooling system pulsed with 0.2 duty cycle, spray water PV cooling system pulsed with 1 duty cycle and steady pulsed PV spray water cooling system increased the PV power output by 25.9%, 27.7% and 33.3% compared to Non cooling PV system. Fig. 7. Showed the PV solar system used.

Fig. 7. PV solar panel used [26]

Chala et al. [41] studied the effect of using PV cooling system in Muscat located in Oman. They made a comparison study between four PV solar panels performance cases, showed in Fig. 8. First case was studying PV panel with an inclination angle in comparable case. Secondly, was studying a PV panel performance with changing its incline angle. The third case was studying the effect of water injection in 30sec time per week and in the next week was in 120sec per week. Fourth PV panel was a solar panel without any cooling or cleaning system. Study results showed that using water injection as a PV cooling process increased energy output by 23.9%.

Sargunanathan et al. [42] studied improving photovoltaic solar panel efficiency and performance and increasing power output under maximum solar irradiance and high ambient temperature using active cooling. They established their study with a comparison study between PV back water cooling, PV front water cooling and simultaneous water cooling of both back and front PV surface. Study results showed that using front cooling, back cooling and simultaneous cooling of back and front PV surface led to a 28.7 ◦C, 18.6 ◦C and 34.7 ◦C maximum reduction in PV operating temperature. Results showed an increase in maximum power output of the 150-Watt PV panel equaled 18.48, 10.70 and 20.56 Watts. In addition to, 15.278%, 8.778% and 16.895% increase in PV efficiency.

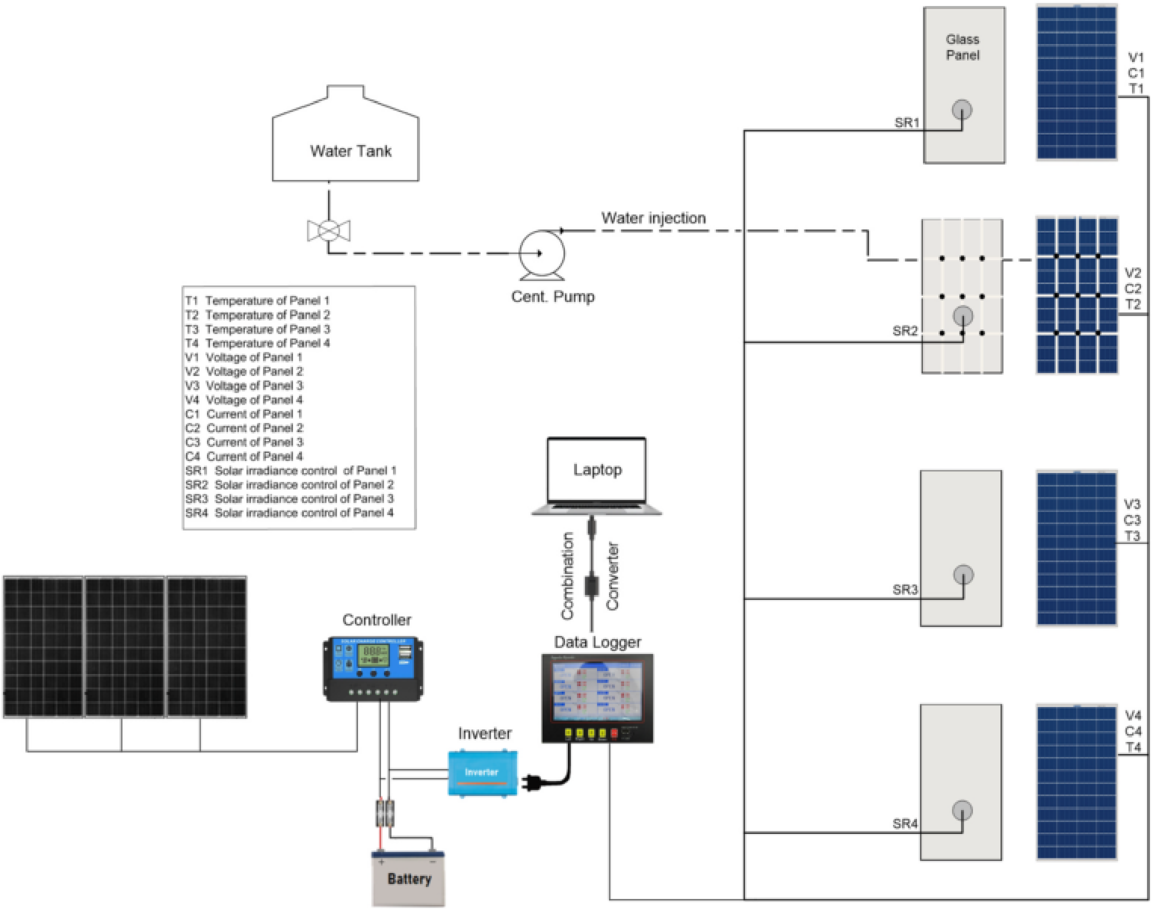

Fig. 8. Schematic diagram of PV solar system used [41]

3.4. Photovoltaic Thermal Solar Systems (PV/T)

Pang et al. [43] studied PV water thermal collector type as illustrated in Fig. 9. By using water mass flowrate equaled from 0.005 kg/sec to 0.25 kg/sec and more than 0.25 kg/sec for finding the optimum condition for good thermal and electrical PV-T efficiency with 15 to 40◦ PV angle. They found that PV temperature decreases with increasing water mass flowrate, and this led to an increasing in PV power output. However, they found that for water mass flowrate more than 0.15 kg/sec, increasing mass flowrate leads to decreasing PV temperature and power output. Study results showed that the optimum amount of mass flowrate was 0.15 kg/sec that produced 11% electrical efficiency and 57% thermal efficiency with 100 L water volume and 25◦ PV panel angle. The extremely expensive price of an integrated PV/T system still restricts its industrial as well as residential applicability, even though the period of payback of a PV/T technique appears shorter than that of a photovoltaic system as well as solar thermal system individually [44]-[47].

Kazem et al. [48] made a comparison study was presented on a PV/T system considering five types of collectors; a hybrid type containing oscillatory and direct systems, a conventional PV/T system, a web type, a direct type, and finally an oscillatory PV/T system type. This comparison was for reaching a better distribution of temperature on the PV/T system. They used 0.02 kg/s mass flowrate, and their results showed that the hybrid system increased the voltage by 4 volts and increased the power by 10.5 watts compared with the conventional system. Maghrabie et al. [49] studied the obstacles that face using building integrated PV systems (BIPVT). The researchers in this article focused on the challenges that face using solar energy for suppling hot and cold water and air for buildings. This article showed ways to utilize the use of PV water- and air-cooling systems for buildings ventilations and air conditioning systems either using PV water heating circuits or by using buildings ventilation based on PV air cooling in winter.

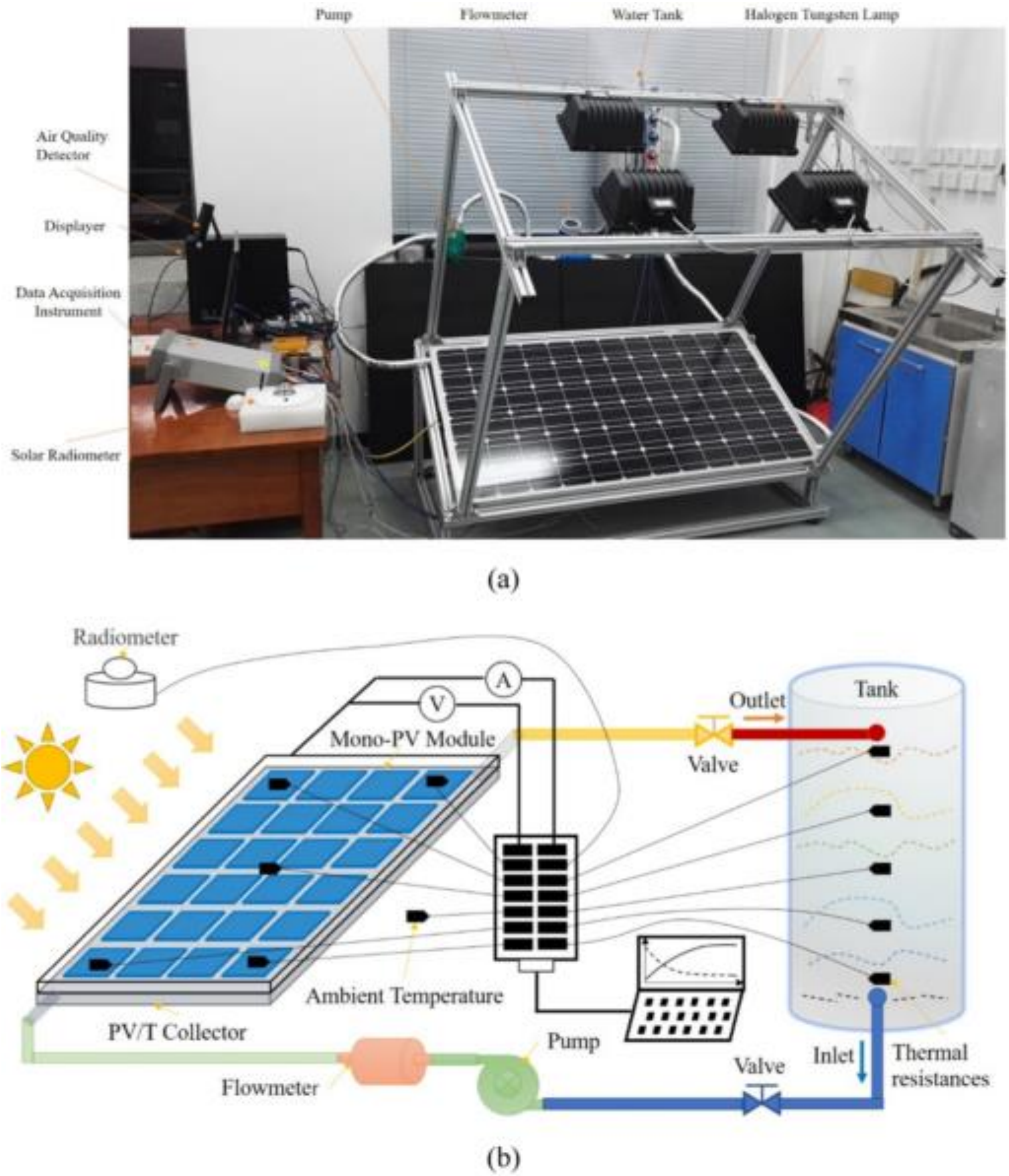

Fig. 9. (a) A real photo and (b) schematic diagram of PV solar system used [43]

Praveen et al. [50] compared the performance of hybrid PV/T with active solar still and the performance of a conventional solar still which was passive without any heat sources. Different amounts of water depth values were considered which were 0.05, 0.10 and 0.15 m. They used a nickel chromium (Ni-Cr) heater in the active solar still to increase the distillate water production. The results revealed that the temperature in the hybrid PV/T active still was higher overall ranges and with 50% higher than the passive solar still system. The power output from the used saline water-cooled PV panel was 30% more than the conventional PV panels. The thermal efficiency and overall thermal efficiency of hybrid PV/T active solar still were respectively 15% and 25% from solar stills without any PV systems.

3.5. Numerical Studies

Valeriu et al. [51] made a numerical study on using an effective type of PV cooling systems. They established their numerical study with the aid of simulating the heat transfer flux between water and Photovoltaic solar panel body using MATLAB software for three layers Photovoltaic solar panel. They focused on water film thickness and velocity of water in their study. They efficiently reached to good heat transfer with 7 mm thickness of water film and 0.035 m/sec water velocity while water inlet temperature equals 20◦C. study results proved that this photovoltaic cooling system produced 1334.5 W thermal power output and 316.56 W electrical power output.

Bin ehtsham et al. [52] made a numerical study of a PV water cooling system using computational fluid dynamics (CFD). Study established in Singapore country using software with circulated water in a heat exchanger. Study established for two different materials copper and steel. Study results showed a 6◦C reduction in PV temperature. With $\frac{2}{3}$ kg/sec water mass flowrate as a best amount with low conductivity materials. Abbas et al. [53] studied evaluation and the annual performance of using hybrid PV/T system coupled with thermal collector with a heat pump which is a solar direct expansion type. They made a prototype of 0.5234 Kw heat pump with 3.5 m2 PV/T thermal collector area. They established their study with real conditions of Karachi city in Pakistan country. They used MATLAB software for making a numerical simulation for their system. Numerical Study results showed an annually electricity generation of 303.51 Kw per hour and a 3213.12 Kw per hour for annually thermal energy generation.

3.6. Experimental and Numerical Studies

Hassan et al. [54] studied experimentally and numerically improving heat transfer process of PV thermal system by varying parameters that have an influence on the performance of PV system such as diameter of the tube, thickness of base plate, flow parameters, electrical and over all parameters. Diameter of water tube was 16 mm. they found that using 1.02 l\min has the highest overall, thermal and electrical efficiency values that was 59.3%, 44.5% and 14.8%. In addition to, they found that increasing Reynolds number value $Re = \frac{\rho V D}{\mu} = \frac{VD}{\nu}$ [55], which is a dimensionless variable depending on dimension of flowing water, mass density, velocity and dynamic viscosity of water results in an increase in the electrical and thermal efficiency. The PV solar system used was illustrated in Fig. 10.

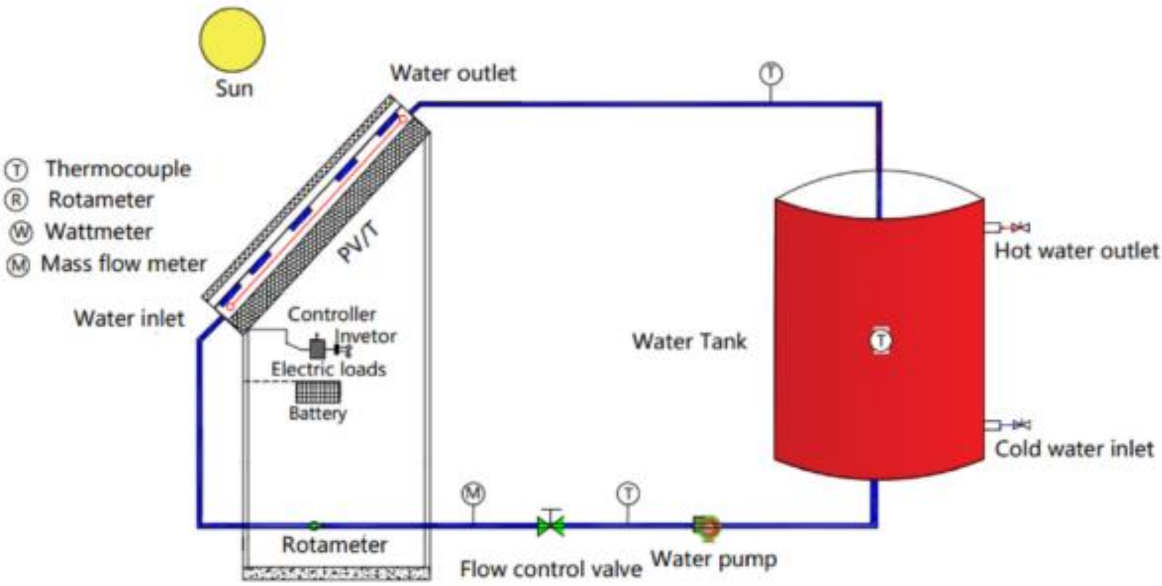

Fig. 10. An illustration of the water-based PV/T test bench schematic [54]

Mohammed et al. [56] made an experimental and numerical study on using water cooling method for decreasing PV temperature, increasing PV efficiency and improving PV performance. They established their study using MATLAB and ANSYS software programs. Numerical study results produced a 7% cooling percentage in PV temperature and a 9.2% improving in PV electrical efficiency in 13th June compared to uncooled PV solar panel. They found that using 0.0075 kg/sec decreased PV temperature by 13% compared to 0.0039 kg/sec case.

P-type and n-type semiconductors are the components that make up the thermoelectric elements. The Peltier effect causes heat to be transferred from the cold side to the hot side of thermoelectric components when electricity passes through them. The Seebeck effect causes these components to function as generators when there is a temperature differential on either side of the thermoelectric device. The process of producing electricity by exploiting the effects of temperature differential on certain semiconductor materials is known as thermoelectricity. Conversely, the thermoelectric device functions as a thermoelectric heat rejection device and produces a temperature differential that is proportionate to the applied DC current when a certain amount of DC current is applied to it [57]. Ejaz et al. [57] focused on using a thermoelectric system for cooling and another for generating electricity with a solar thermoelectric system. See beck and Peltier effects were used with water cooling to cool PV and generate electricity in addition to using maximum power point tracking (MPPT) strategy. Using thermoelectric systems with PV solar systems increased PV efficiency by 9% at 25◦C ideal temperature and by 4.1% at 55◦C extreme temperature. Direct Current to Direct Current (DC-DC) converter was used with MPPT for enhance increasing PV power output. Polus et al. [58] made a pulse levels of feeding water temperature set point which it was 20, 25, 30,19 35 and 40 ◦C with three levels of salinity of feed water which was firstly 1500, secondly was 3000 and thirdly was 4500 in mg/L. using brine cooling showed a 0.55 maximum Reverse osmosis (RO) recovery factor was obtained with 1500 mg/L for the saline feed water and 40◦C temperature set point. Results showed a 20% increase in PV electrical efficiency compared to uncooled PV solar system.

Duan et al. [59] established a PV cooling solar system showed in Fig. 11. They established their study using a low-pressure swirl flow-atomizing pressurizer. In this article they studied effect of atomizer on spray angle, size of droplet, rate of flow and velocity value at different pressure and size values. Study results showed a 10.52% increase in electrical efficiency and a 6.57% increase in power output.

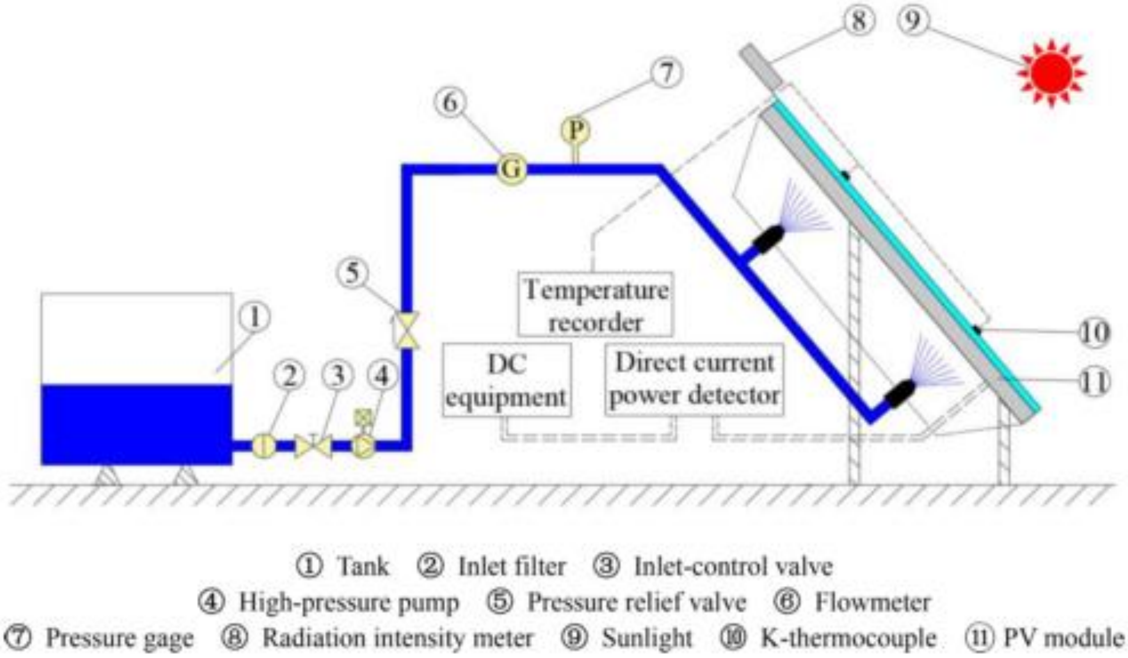

Fig. 11. PV solar system used schematic [59]

Hossin and Attia. [60] Studied using PV water cooling system in United Arabic Emirates (UAE) location conditions. In this article they used a two – 100 W PV solar panels with automated PV water cooling system. Study result showed a 14.6 ◦C drop in PV temperature and a 12% increase in PV power output. Mostakim et al. [61] established an experimental study focused on using an automated

PV water cooling system by controlling the water flow passing over a PV solar panel. They found that 45º PV angle was the optimum PV tilt angle that resulted in a 70.6% highest thermal efficiency. Study results show a 2.53 increase in the value of PV efficiency from 14.6% to 17.13%. Naqvi et al. [62] established a PV water cooling system based on used mist type of designed water nozzles. They established their study based on natural and forced cooling water circulation using submerged water pump. Study results produced a 7% highest PV efficiency gain for natural cooling water circulation and a 9.2% highest PV efficiency gain for forced cooling water circulation.

Hasan et al. [63] established a PV panel system with water cooling heat sink in summer season of Iraq country. They found that PV temperature increases from 65 to 73◦C if solar radiation increases from 500 w/m2 to 960 w/m2. They studied the impact of varying the impact of varying the amount of water mass flowrate from 4 to 16 L/min in PV cooling process. Study results showed an increase in electrical efficiency from 11.7 to 14 % and increasing in power output from 55 to 75 watts. De Vanna el al. [64] established a PV water spray cooling system. They established their study focusing in some parameters such as number of nozzles, location, geometric parameter, distribution of PV temperature, formation of limstones, properties of glass, consumption of water and power output. They made their study using 90◦ spray angle with 1.5 bar water supply. They used ON-OFF mode of spray from 30 sec to 180 sec. study results increased efficiency 2.09% with an increase percentage equaled 18.69% compared to uncooled PV panel electrical efficiency. in addition to, a 24 ◦C temperature reduction in addition to increasing power output by 33.43 watts.

3.7. Thermal Model of a PV Water Film Cooling System

To examine the impact of water cooling on photovoltaic system performance, a mathematical model must be suggested. The steady state energy balance incorporating different heat transfer mechanisms can be described as shown in equation by treating the PV module as a control volume [65].

$$q_s = q_c + q_r + P + q_w \tag{3}$$

Where q_s is the solar radiation that is absorbed and can be measured as [66]:

$$q_s = (1-\rho).G.A_s \tag{4}$$

Where A_s is the module surface area, G is the incident total irradiance on the panel, and ρ is the reflectivity of the module surface, which is shown to be equal to 0.12 by [67].

P, it represents the creation of electrical power in the following equation [66]:

$$P = G.A_s.\eta_{PV} \tag{5}$$

Where the module efficiency, represented by η_{PV} in the equation above, depends on the PV temperature as the following equation [66]:

$$\eta_{PV} = \eta_{ref}\,.\left(1-\beta_{ref}.\left(T-T_{ref}\right)\right) \tag{6}$$

According to [68], η_{ref} and β_{ref} should be equal to 0.015 and 0.0041, respectively.

The heat released by convection is known as q_c . The panel is divided into two segments: the front and rear surfaces, as it is positioned above ground. Both forced and free convection should be considered in order to determine the total convective heat transfer coefficient as illustrated in the following equations [66].

$$q_{c,front} = h_c.A_{front}.\left(T_{front}-T_{air}\right) \tag{7}$$

$$q_{c,rear} = h_c.A_{rear}.(T_{rear}-T_{air}) \tag{8}$$

$$h_c = \sqrt[3]{h_{c,forced}^3 + h_{c,free}^3} \tag{9}$$

The Nusselt number for free convection on the bottom surface is expressed in the following equation as recommended in [69].

$$Nu = \left[0.825 + \frac{0.387 Ra^{\frac{1}{6}}}{\left[1 + (0.492/Pr)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right]^2 \tag{10}$$

Additionally, as mentioned in [70], the Nusselt number for free convection for the upper surface is calculated in the following equation:

$$Nu = 0.14 \left[(Gr.Pr)^{\frac{1}{3}} - (Gr_{cr}.Pr)^{\frac{1}{3}} \right] + 0.56(Gr_{cr}.Pr cos(\theta))^{\frac{1}{4}} \tag{11}$$

Where the panel is exposed to wind, forced convection occurs on both the upper and bottom surfaces in addition to free convection. The forced convective heat transfer coefficients are displayed as the following equations [71]:

$$h_{c,forced} = 3.3w + 6.5 \qquad in\ windward\ locations \tag{12}$$

$$h_{c,forced} = 2.2w + 8.3 \qquad in\ leeward\ locations \tag{13}$$

Where w represents speed of the wind.

The radiative heat dispersion from the module surface is denoted by q_r. Since it refers to radiation with the sky and ground, the associated view parameters are detailed in the following equations:

$$q_{r,sky} = \epsilon . F_{sky} . \sigma A_s . \left(T^4 - T_{sky}^4 \right) \tag{14}$$

$$q_{r.ground} = \epsilon . F_{ground} . \sigma A_s . \left(T^4 - T_{ground}^4 \right) \tag{15}$$

$$F_{front-sky} = \frac{1}{2}(1 + cos\beta) \tag{16}$$

$$F_{front-ground} = \frac{1}{2}(1 - cos\beta) \tag{17}$$

$$F_{rear-sky} = \frac{1}{2}(1 + \cos(\pi - \beta)) \tag{18}$$

$$F_{rear-ground} = \frac{1}{2}(1 - \cos(\pi - \beta)) \tag{19}$$

Lastly, q_w illustrates how water-cooling works. If cooling occurs, this term is included in the equation; otherwise, it equals zero. It's expected that a thin layer of water, the same thickness throughout, flows over the panel's top surface to provide cooling. q_w Can be determined using the following equation [66]:

$$q_w = h_w . A_s . (T - T_w) \tag{20}$$

The formula that follows [72] is implemented to determine the convective coefficient of heat transfer for the water-based film and Photovoltaic surface h_w.

$$Nu_x = 0.332 Re_x^{0.5} Pr^{0.33} \tag{21}$$

The Reynolds number can be calculated using the following two equations [66]:

$$Re_x = \frac{\rho_w . v . x}{\mu} \tag{22}$$

In the Reynolds number equation, velocity is computed as follows:

$$v = \frac{Q}{y_w . B} \tag{23}$$

Where y_w (thickness of water film) as illustrated in [72] can be determined using the following equation:

$$y_w = \sqrt[3]{\frac{Q^2}{\text{g}.\text{B}^2}} \tag{24}$$

Where in this study, the thin layer of water flow over the panel surface is regarded as homogeneous and laminar. High accuracy computations can also be obtained by ignoring the nonuniformity (considered a laminar) of the flow across the panel's surface, as per reference [72]. The following Equations can be used to express the pump power usage [66]:

$$P_{pump} = \frac{Q . H_{total} . \text{g}. \rho_w}{\eta_{pump}} \tag{25}$$

$$H_{total} = H_{elevation} + H_{loss} \tag{26}$$

Where $H_{elevation}$ it is the pump's and intermediate tank's height difference. H_{loss}, which is represented by the Hazen Williams equation as illustrated in the following equation [55], is the head loss via the water pipes:

$$H_{loss} = k . Q^n \tag{27}$$

Since the value of k is determined as follows: D is the pipe diameter, L is the pipe length, n is 1.852, C_{hw} is equal to 130, and C_k is 10.67 as illustrated in [66].

$$k = \frac{(C_k . L)}{C_{hw}^{1.852} . D^{4.87}} \tag{28}$$

The following Table 1 presents the latest study made on utilizing PV water cooling mechanisms for enhancing performance improvement.

Table 1. Summary of previous studies made on using different PV water cooling systems

Authors	Cooling system type	Type of study	Main Results		
			Temperature reduction	**Increase in output power**	**Increase in electrical efficiency**
(Elnozahy *et al.* 2015) [33]	Water cooling system	Experimental	20◦C reduction in PV surface temperature	---------	---------
(Piotrowski *et al.* 2020) [25]	Water cooling system	Experimental	--------------	-----------	30% increasing in PV efficiency

Authors	**Cooling system type**	**Type of study**	**Main Results**		
			Temperature reduction	**Increase in output power**	**Increase in electrical efficiency**
(Shalaby *et al.* 2022) [35]	Back surface water cooling system	Experimental	-------------	14.1% increasing in power output	2.4 increase in efficiency with a 13.79% increase percentage
(Kherkhar *et al.* 2022) [73]	Thermoelectric cooling system	Experimental	5◦C reduction in PV surface temperature	-----------	-----------
(Yi Mah *et al.* 2019) [38]	Water film cooling system	Experimental	----------------	15% increasing in power output	------------
(Kazem *et al.* 2021) [48]	a comparison study between a hybrid type, a conventional PV/T system, a web type, a direct type, and finally an oscillatory PV/T system type	Experimental	---------------	Increased the voltage 4 volt and the power by 10.5 watts	------------
(Tina and Scavo 2022) [74]	Comparison between floating and ground PV systems with dual solar tracking systems which studied in two cases mono and bifacial systems. The comparison study was made in two locations one was in ANAPO dam in Italy and the other was Aar dam Germany.	Experimental	---------------	increased the PV gain with 3% and 4% in both locations while using natural cooling or floating systems increased the gain with 5% and 4% in both locations	-----------
(Hadipour *et al.* 2021) [26]	A comparison study between different PV cooling cases: un cooled PV case, steady water-cooling case, cooling with pulsed water with duty cycle equaled 0.2 case and cooling with pulsed water with duty cycle equaled 1 case.	Experimental	--------------	Maximum increase in PV power output with 33.3 %, 27.7% for pulsed water cooling with 1 duty cycle and 25.9% for pulsed water cooling with 0.2 duty cycle compared to uncooled PV case.	--------------
(Pang *et al.* 2019) [43]	They studied varying water mass flowrate from 0.005 to 0.25 kg/sec on PV water thermal collector system	Experimental	-----------------	-------------	They found using 0.15 kg/sec was the optimum amount of water mass flowrate the produced 11% electrical

Authors	Cooling system type	Type of study	Main Results		
			Temperature reduction	**Increase in output power**	**Increase in electrical efficiency**
					efficiency and 57% thermal efficiency.
(Praveen *et al.* 2017) [50]	Made a comparison study between two solar stills, the first one was a hybrid PV-T active solar still and the other was a passive conventional solar still.	Experimental	----------------	30% increase in power output	--------------
(Lucas *et al.* 2019) [39]	They made a PV solar system based on front surface PV water cooling using a compression chiller and back surface PV air cooling using a solar chimney.	Experimental	15◦C amount of cooling	--------------	10% increase in electrical efficiency
(Hasan *et al.* 2022) [63]	They established a PV panel system with water cooling heat sink in summer season of Iraq country. They studied varying the amount water mass flowrate from 4 to 16 L/min on PV system performance and efficiency.	Experimental	--------------	20 watts increase in PV power output.	A 2.3 increase in PV electrical efficiency and a 19.69% increase percentage compared to uncooled PV panel electrical efficiency
(De Vanna *et al.* 2021) [64]	They established a PV water spray system, focused in some parameters such as number of nozzles, location…. etc. they used a 90◦ spray angle with 1.5 bar water supply. They used ON-OFF mode of spray from 30 sec to 180 sec.	Experimental	A 24 ◦C temperature reduction and	33.43 watts increase in PV power output.	A 2.09 increase in PV efficiency which equaled a 18.69% increase percentage compared to uncooled PV panel electrical efficiency
(Bin ehtsham *et al.* 2021) [52]	Made a numerical study of a PV water cooling system using computational fluid dynamics CFD in Singapore using software with circulated water in a heat exchanger	Numerical	A 6◦C reduction in PV temperature.	-------------	---------------
(Masalha *et al.* 2023) [36]	Using two different materials copper and steel. They studied using a porous media for PV cooling system	Experimental	a 35.7% maximum reduction in PV	a 9.4% increasing in	--------------

Authors	Cooling system type	Type of study	Main Results		
			Temperature reduction	Increase in output power	Increase in electrical efficiency
	with different porosities and different water mass flowrates and its influence on PV back surface temperature, electrical efficiency and power output.		back surface temperature	PV power output	
(Sargunanathan *et al.* 202-0) [42]	Studied the influence of using an active cooling on PV efficiency and performance. They made a comparison study between PV front water cooling, PV back water cooling and simultaneous water cooling of both back and front PV surface.	Experimental	A 28.7 ◦C, 18.6 ◦C and 34.7 ◦C temperature reduction.	An increase of 18.48, 10.70 and 20.56 Watts in PV power output	A 15.278%, 8.778% and 16.895% increase in PV efficiency.
(MOHAMMED *et al.* 2022) [56]	They studied the influence of using water cooling on PV /performance, power output and efficiency. They used ANSYS and MATLAB software program in their numerical study.	Experimental and Numerical	a 7% cooling decrease in PV temperature	--------------	a 9.2% increase in PV electrical efficiency
(Polus *et al.* 2023) [58]	Study using spray water cooling with zigzag geometry for improving PV efficiency and performance.	Experimental and Numerical	A 5◦C reduction in feed water temperature	A 2.25% increase in PV power output	A 20.25% increase in PV efficiency.
(Duan *et al.*, 2024) [66]	They studied effect of using a low-pressure type of swirl atomizing flow pressurizer on a PV cooling system performance.	Experimental	----------------	Increased the power output by a 6.57%.	Increased PV electrical efficiency by 10.52%
(Hossin and Attia, 2024) [67]	They studied the effect of using water cooling system on PV solar system performance.	Experimental	Reduced the temperature by 14.6 ◦C	Increased the power output by 12%.	--------------
(Mostakim *et al.*, 2024) [61]	Studied using PV water cooling method for PV solar system at various water flowrate values.	Experimental	----------------	--------------	a 2.53 increase in PV efficiency equaled 17.33% increase percentage

Authors	Cooling system type	Type of study	Main Results		
			Temperature reduction	Increase in output power	Increase in electrical efficiency
(Chala, sulaiman and Al Alshaikh, 2024) [70]	Studied the effect of changing PV cooling water injection time on PV solar system performance	Experimental	---------------	Increased PV energy output by 23.9%.	-------------
(Ahmed *et al*., 2023) [71]	Studied the influence of changing velocity of wind, solar irradiance, deposed dust amount and amount of cooling water flowrates values on a 50 W PV system performance	Experimental	---------------	Increased amount of PV power output by 20.47%	Increased efficiency value of exergy, and energy output efficiency by 37.5% and 12%.

4. Effect of Using Temperature-Controlled PV Water Cooling System on PV Performance

There are two main control schemes that may be used to analyze the control design strategies that researchers have created and proposed for a PV cooling control system: open-loop control and closed-loop control. Closed-loop or feedback-loop control is a control technique that has been frequently developed for Photovoltaic cooling control systems in which the output signal is feed backed and compared to a desired set point. On the other hand, open loop control system is not require any feedback signals in which the output signal is not depend on any reference set point values. The PV cooling mechanism was able to modify its operation in accordance with the intended output response thanks to this kind of control technology. There are three paradigms that can be used to classify close-loop control strategies in PV cooling systems [75]:

- Classical type of control: This design strategy is easy to adopt and appropriate for low-order systems. With this kind of control, users can learn what happens when the settings of traditional proportional (P), proportional-integral (PI), batch, and ON-OFF controllers are changed.
- Modern type of control: This design methodology can be used to sophisticated, high-order systems. A specific kind of this control is unable to tell users of the effects of changing the controller's parameters. Batch control, robust control, and optimum control are the methods. But with the Photovoltaic cooling control system, the researcher just used the best control possible.
- Method for controlling using artificial intelligence (AI): This design approach makes use of clever methods like neural networks, fuzzy logic, and metaheuristics. This style of issue solving imitates how humans and the natural world adapt to each other's lives and processes. Many of these methods are frequently used with PID controllers.

The following Fig. 12 shows a classification of control systems used in PV cooling mechanisms.

Implementation of control systems for PV cooling system was another direction for researchers to improve the PV efficiency and performance. Different types of control platforms were used such as Arduino unit and microcontroller chip, most of previous studies focused on utilizing classical control systems for PV water cooling systems are presented in this section as follows:

Sahu et al. [77] found that PV panel temperature between 15◦C to 35◦C led to the highest efficiency. Therefore, they designed and implemented a control system using an Arduino microcontroller, A Tm- pt100 type temperature sensor and a special type of light dependent resistors

(LDRs) for sensing solar intensity for reducing PV temperature and removing PV surface accumulated dust. PV cooled panel reached to 37ºC in 5 to 7 min compared to 77.6 ºC for uncooled PV panel that increased PV lifetime and improved its performance. Prasad et al. [78] studied the enhancement of ON-OFF temperature controlled PV water cooling solar system for irrigation as illustrated in Fig. 13. As three sensors voltage, current and temperature sensors were attached to each cooled and uncooled PV panel for studying its performance. It was found that the temperature of the PV surface depends on three factors: radiation coming from sun, location of the module, and temperature of the PV surface. Arduino controller was used for monitoring the performance of the panel by controlling the motor/pump to reach a desired water mass flowrate at 0.0028 kg/s. The cost of Arduino monitoring system was 10$ with 50% decreasing in cost compared to other monitoring control systems. In addition, the electrical efficiency of the panel was improved by 17 %.

Laseinde et al. [29] established an automated water spray cooling system for a PV solar system. They established their study with a panel of 17 watts and 12 volts dc directed to the northwest direction and placed with tilt angle equals 30◦. Arduino microcontroller was also used for increasing the electrical efficiency of PV modules. Their results presented an increase in the PV array efficiency by 16.65 %. Kamarudin et al. [79] developed an automated control system which was an ON-OFF control type for cooling PV modules as illustrated in Fig. 14. To improve the efficiency of the panel and increase the power output. Their control system was incorporated with internet of things (IOT) technology. Their results showed an improvement in the PV efficiency by 17.08%.

Etier et al. [80] investigated the properties of photovoltaic/thermal (PV-T) system. It was found that the operating temperature has a great influence on PV module performance. Therefore, they developed an automated cooling control system to increase the electrical efficiency of the PV module. They used an active cooling method with water and the Arduino microcontroller as the main controller. Their results revealed that the electrical power of the PV module was increased with 6.86 % by decreasing the PV module temperature by 26 %. Their study produced a decrease in the PV surface temperature to approximately 49◦C at noon which was related to temperature of ambient (31◦C) which was taken in their study and a radiation of 690 watts per square meter. They managed to decrease the PV panel surface temperature by 10◦C compared to the conventional PV panels that reach 59◦C. the PV-T flowchart was drawn and showed in Fig. 15.

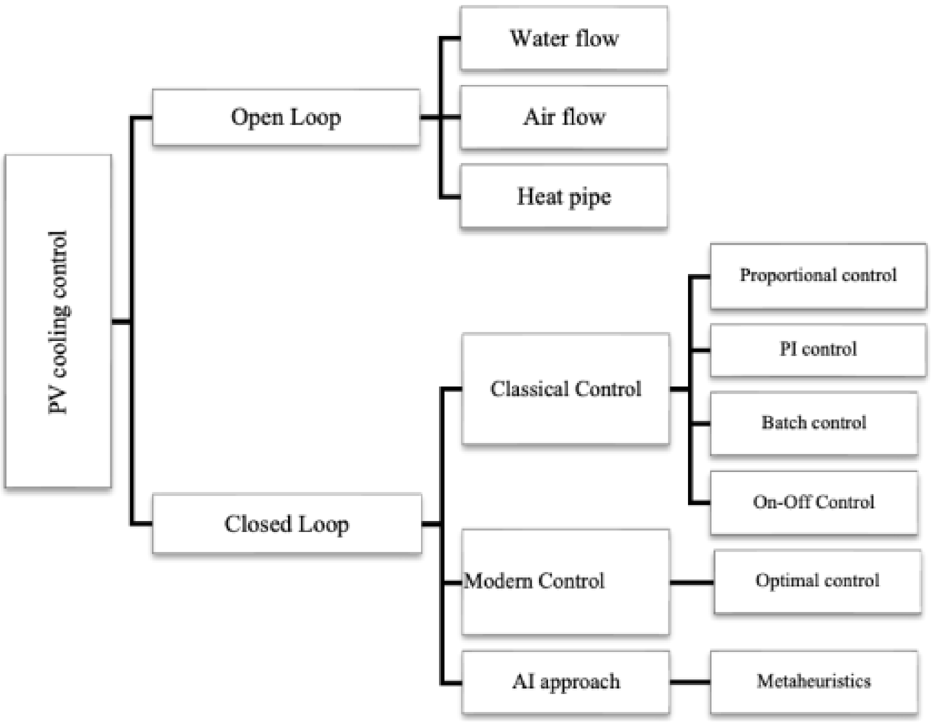

Fig. 12. Control methods utilized for PV cooling systems [76]

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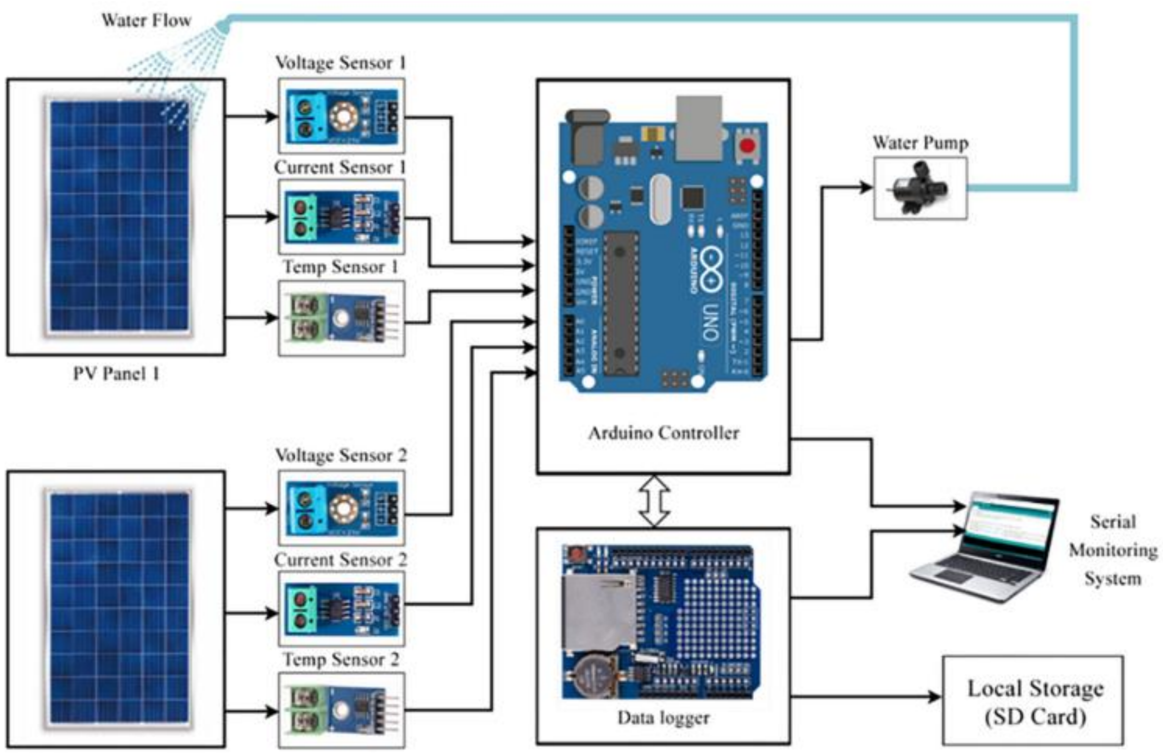

Fig. 13. The general design of the Arduino controller system, complete with many sensors including voltage, current, and temperature, is displayed [78]

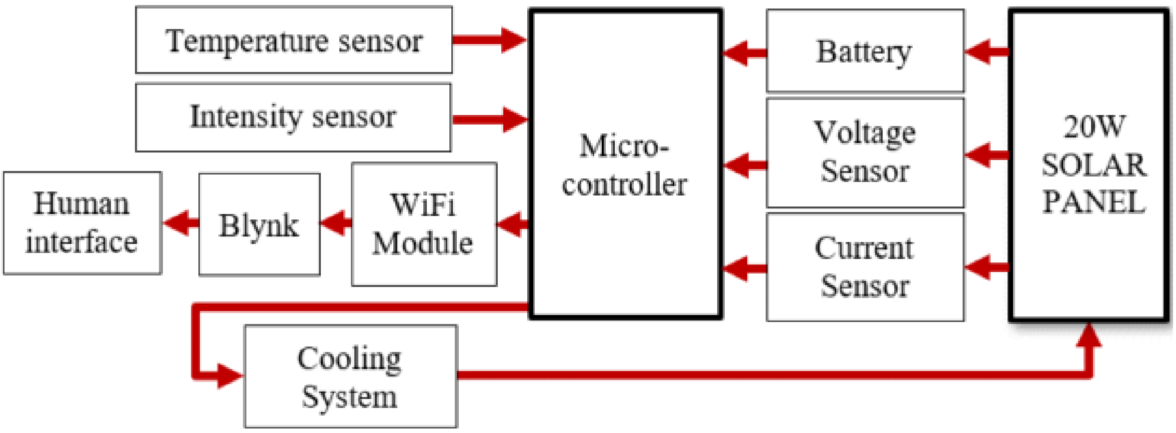

Fig. 14. System block diagram [79]

Jamil et al. [81] studied the enhancement of the performance of a floating PV module was investigated using Arduino Nano controller. Two PV cases were considered: one was on the land area and the other was on the water surface. Their results revealed that the automated cooling system increased the power output in floating type more than the used on the land area. It was found that the floating PV module was a good alternative method to save usage of the land, safer, and don't produce any pollution. Kadhim et al. [82] used an underground water tank in their approach in which four water cooling techniques were developed. These techniques were back panel surface water cooling (case 1), front and back surface water cooling (case 2), front and back surface water cooling using Arduino microcontroller (case 3) and repeating the latter case using different water flowrates conditions (case 4). They established their study using three PV panels that panel A was studied without using any cooling systems, panel B was studied by using spray cooling method and panel C was studied by using evaporative cooling method. Results showed That for panel B of spray cooling method the maximum power output and the electrical efficiency of the PV panel in the five cases was

36 W and 7.47% for Non cooled case, 37.2 W and 7.73% for case (1), 37.69 W and 7.83% for case (2), 42.45 W and 8.82% for case (3) in addition to 44.39 W and 9.2% for case 4. And for panel C of evaporative cooling method the maximum power output and the electrical efficiency of the panel in the five cases was 36 W and 7.47% for Non cooled case, 36.59 W and 7.6% for case (1), 37 W and 7.68% for case (2), 41.63 W and 8.65% for case (3) in addition to 41.78 W and 8.67% for case (4).

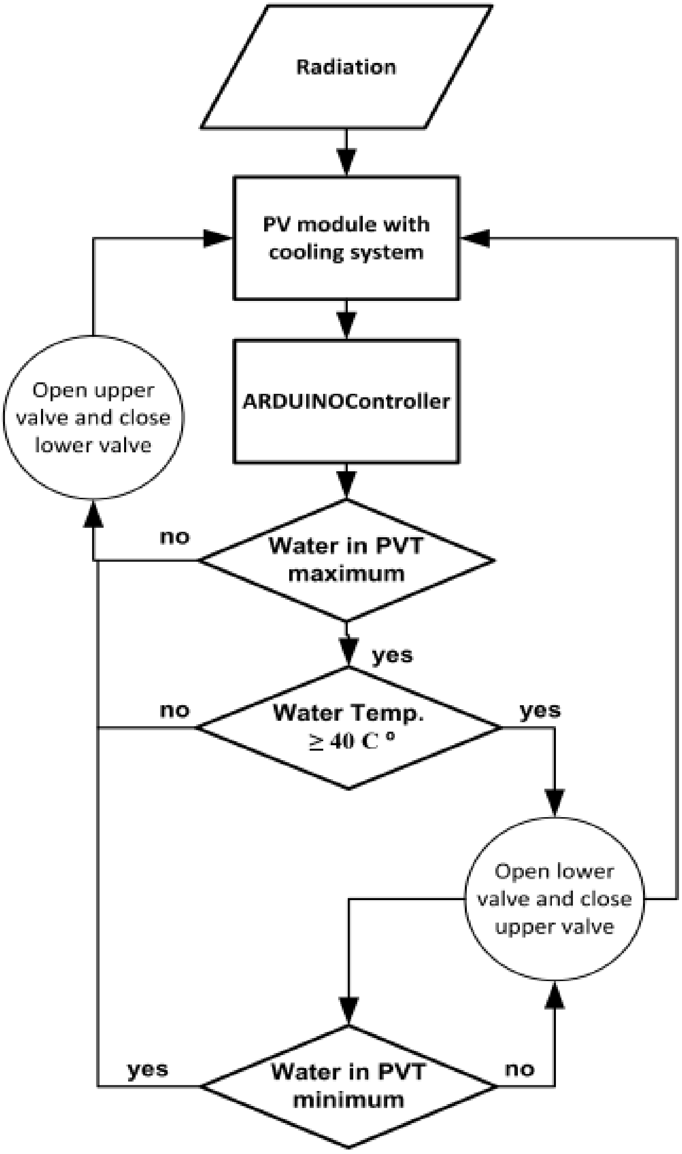

Fig. 15. Flowchart of the PV-T system processes [80]

Hajjaj et al. [83] used the Arduino microcontroller for water cooling of the PV system. They developed their system by circulating water on the PV backside. The PV surface temperature was kept (2 – 3 degree) higher than the temperature of used circulating water. The cooling control system kept the PV temperature equal to 24◦C which was decreased from 48◦C as well as increased the PV efficiency by 0.046%/◦C. Samal et al. [84] found that increasing the PV surface temperature led to decreasing the efficiency with inverse proportionally relation. They found that the excess heat can reduce the PV efficiency. They investigated the ON-OFF and the PID control for controlling the PV temperature to a desired value for increasing the PV efficiency. Therefore, they developed a facility to set the PV at any desired temperature value. Harahap et al. [85] presented a comparison study between two PV systems. In the first system, active cooling system was used. In the other one, the passive cooling was used. Their results proved that the active cooling increased the voltage by 2.087%, increased the current by 11.02%, and increased the output power to 13.56% compared with the passive cooling case.

Nabil and Mansour. [86] Found that increasing the PV temperature led to decreasing in the PV electrical efficiency. They found that for every one degree increasing in temperature, the efficiency decreased by 0.42%. In their paper, a comparison study was presented between four cases of PV systems. These systems were as follows: the PV fan cooling system, back surface PV water cooling system using a copper heat exchanger, using of a Nano fluid which is copper oxide, and finally, the front surface PV water cooling system using a copper heat exchanger. An Arduino microcontroller has been used in this article for controlling the PV surface temperature. The researcher used ON-OFF control system with the aid of one wire temperature sensor. Abdullah et al. [87] executed a comparative study between four cases for an integrating photovoltaic thermal-wall (PV/TW) solar system. These cases were as follows: without cooling, water cooling, air cooling, and combined water air cooling system. Their results showed that using the type of water cooling produces the highest thermal efficiency was 39.81% however the highest electrical efficiency of PV panel was produced by using combined water air cooling system which increased by 11.69%. The overall efficiency was the highest for the PV panel by using water cooling only system and it was equal to 51.40%. The researcher established his study using Arduino microcontroller. He used ON-OFF control system in addition to using speed controls to control fan and water pump speed.

Samal et al. [88] used water cooling control systems for controlling PV surface temperature. They used the ON-OFF and PID control systems and established their study using Arduino unit, water heater for heating in case of low PV surface temperature, fan for cooling in case of high PV surface temperature, and resistance temperature sensor (RTD) of type PT100. Their study could obtain the desired PV surface temperature and improved the performance. Yacoub et al. [89] used a control system with PV water cooling system for enhancing the PV performance and the increasing PV efficiency. The researchers made a comparison study between the controlled water-cooling PV systems and the non-cooled PV systems. The ON-OFF control system was used in this research work. Study results showed a reduction of 10.55% in the PV temperature for the cooled PV-T system compared to the conventional PV systems. Furthermore, the electrical efficiency value was increased by 1.4 equaled 12.61% for the cooled PV-T system compared to the non-cooled PV system. The studies flow chart was drawn and showed in Fig. 16.

Alshibil et al. [90] established a PV-T system with a controlled water cooling system was used for increasing the PV efficiency and performance. They built their PV-T system and made a simulation for the PV-T system using TRNSYS simulator. In addition, a comparison study was deducted between the use of ON-OFF and the PID control systems. For implementing their system, Arduino array unit with K type temperature sensor were used. Their study showed that the electrical performance of the PV-T system with ON-OFF control system was lower than using the PID control system. The thermal performance of the PV-T system was the highest in the case of ON-OFF control type compared with the PID control type. In other meaning, the thermal performance in case of ON-OFF type-controlled PV-T system was 6.1% higher than PID controlled PV-T and 14.5% higher than systems without daily using water in PV-T systems. It was found that the optimum tilt angle was 30◦ for a city in Hungary.

Mohamed et al. [91] made a comparison study was developed between using PV system with cover sheet made of Nano ceramic material and using controlled PV water cooling system. Their study was established using an Arduino unit, digital temperature sensor, water pump, a Liquid Crystal Display (LCD) screen for monitoring the PV parameters. It was found that using PV controlled water-cooling systems enhanced the PV performance unlike using non ceramic materials which did not achieve any improve in the performance. Using control system in PV cooling improved the maximum power output by 45.7% compared to non-cooled PV system.

Kusuma et al. [92] studied solving Photovoltaic PV solar panel temperature change. They made their study using Peltier and combined water- and air-cooling techniques. In air cooling technique they used a heat sink which was a coating a Peltier at the PV panel backside. In water cooling technique they used a water pump for cooling the PV surface temperature. They have done their research with a tilt angle equal 24.6◦ with northern orientation. He used an Arduino microcontroller for an ON-OFF controlled cooling system. He found that using controlled cooling system is an active method when temperature exceeded 40◦ C and not active method at temperature being below 38◦ C. finally, they found that the controlled cooling system used reduced power losses by 4% and increased the power output by 1.553 watts. Singh et al. [93] concerned their study on using automated controlled cooling systems for concentrated PV panels using reflecting mirrors. Studies established in April of 2022 year at the region of (Azamgarh - Ultra Pradesh) in India country.

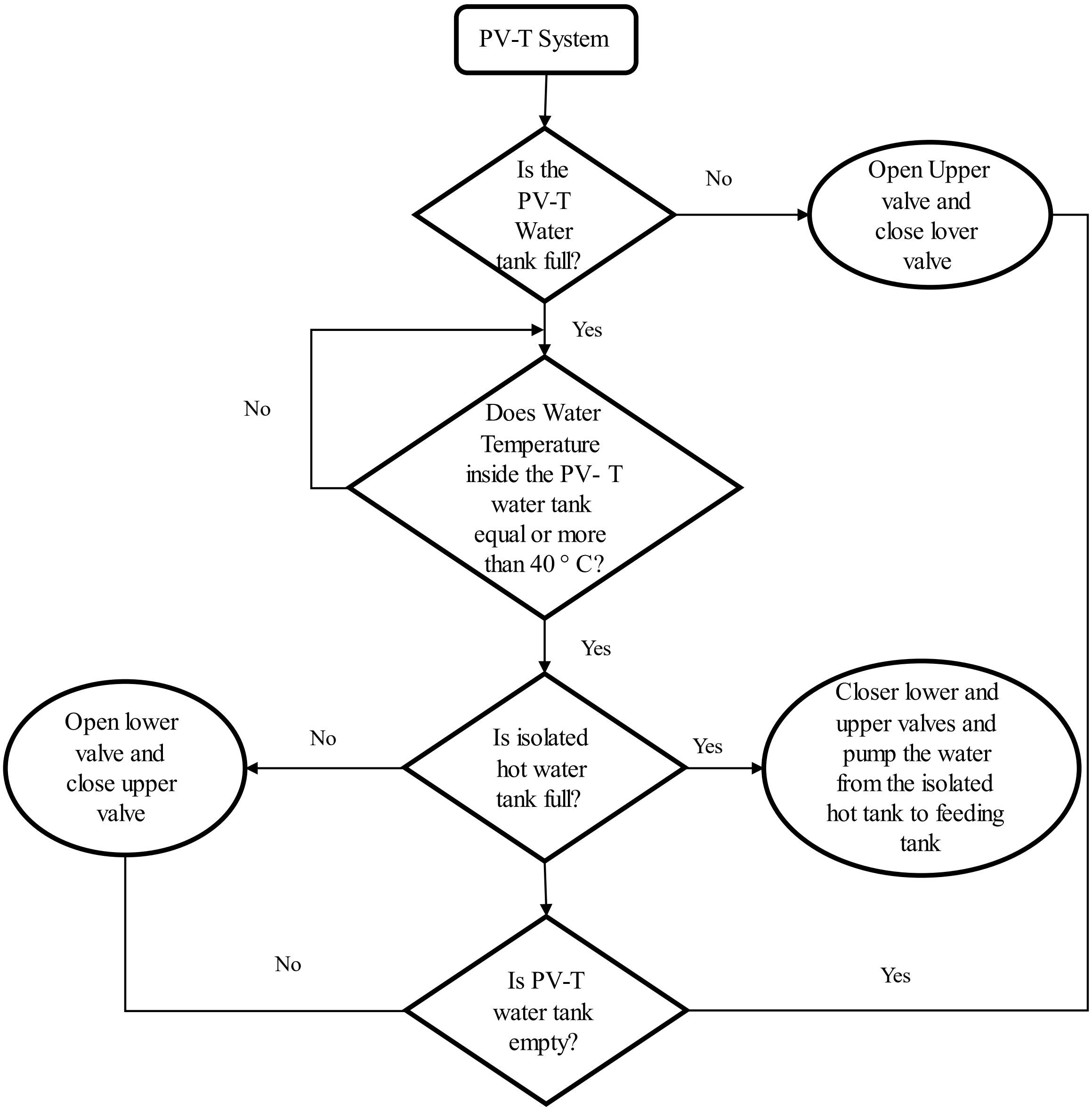

Fig. 16. PV-T system flowchart used [89]

Researchers established their studies with four models, no 1 was a conventional PV cooling system, no 2 was an automated PV cooling system, No 3 established using reflecting mirrors, finally, No 4 was established using both reflecting mirrors and automated PV cooling system. In model No 2 PV temperature was reduced by 14.7◦C compared to model No 1. In addition to, using model 4 reduced PV temperature by 13.74◦C compared to model 3. Finally, they found that using the model 4 had 13.3 % electrical efficiency which was 15.01%, 8.3%, 13.3% higher than model 3, 2 and 1.

Novak et al. [94] built a smart controlled PV water cooling system for increasing PV efficiency and improving performance. The researchers in this article established their study by using a microcontroller unit called (ESP8266). Study results produced an improvement of PV performance equals 14 %. Wang et al. [95] studied the ability of improving performance of PV solar panels and increasing the production of PV electricity. They established their study using a PV controlled water-cooling system using an Arduino microcontroller unit that based on pulse width modulation PWM for regulating the amount of water flowrate for cooling PV solar panel. They used an infrared temperature sensor called (MLX90614). They built an ON-OFF control system type. Study results showed a reduction in the PV temperature by 15.3 % as well as 14.4 % increasing in PV power output. Fig. 17. Shows block diagram flowchart of PV system used.

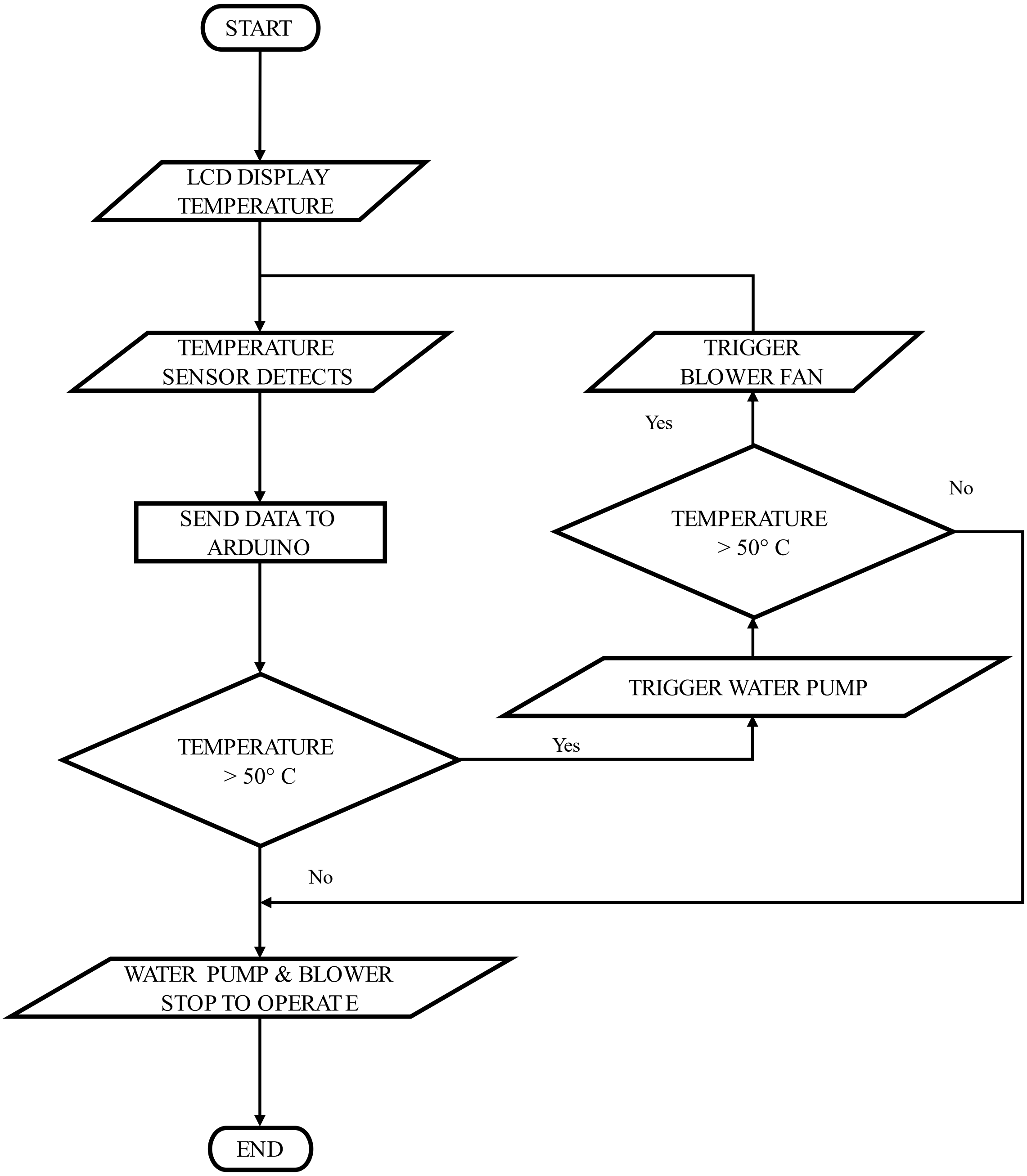

Fig. 17. Block diagram flowchart of PV solar system [97]

Winardi et al. [96] studied monitoring of the PV solar panel parameter in high temperature conditions as well as using a PV water cooling control system for enhancing improving PV performance and increasing PV electrical efficiency. They do their study with the aid of internet of things technique (IOT), Node MCU which is based on Arduino microcontroller in which embedded a

WIFI chip called (ES8266), a sensor called (DS18B20) for sensing room temperature which is taken 35◦C as a temperature set point. PV system data was stored and monitored using BLYNK application. The control system used was an ON-OFF control system type. They made a comparison study between three PV system cases. Case No 2 taken in 23th of March 2022 with set point temperature equals 35◦C that produced a reduction in PV temperature equals 8.79◦C and case No 3 taken in 24th of March 2022 with set point temperature equals 30◦C that produced a reduction in PV temperature equals 8.69◦C compared to case No 1 that was taken in 29th of March 2022 with PV average temperature equaled 41.57◦C. Azmi et al. [97] studied cooling PV temperature using a hybrid method of PV cooling using water and air. They established their study using an ON-OFF control methodology using an Arduino microcontroller with 50 Celsius degree PV temperature set point. Study results showed a 4.5% improve in PV efficiency compared to uncooled PV system.

Yusoff et al. [98] established hybrid cooling system for a PV solar panel using both active and passive cooling types with the aid of using an Arduino microcontroller. They made their study using front surface sprinklers PV water cooling as an active PV cooling besides using beads of hydrogel combined with a back side heat sink cooling system. Study results showed an increase in PV power output equaled 4.07 watts. Operation system flowchart used showed in Fig. 18.

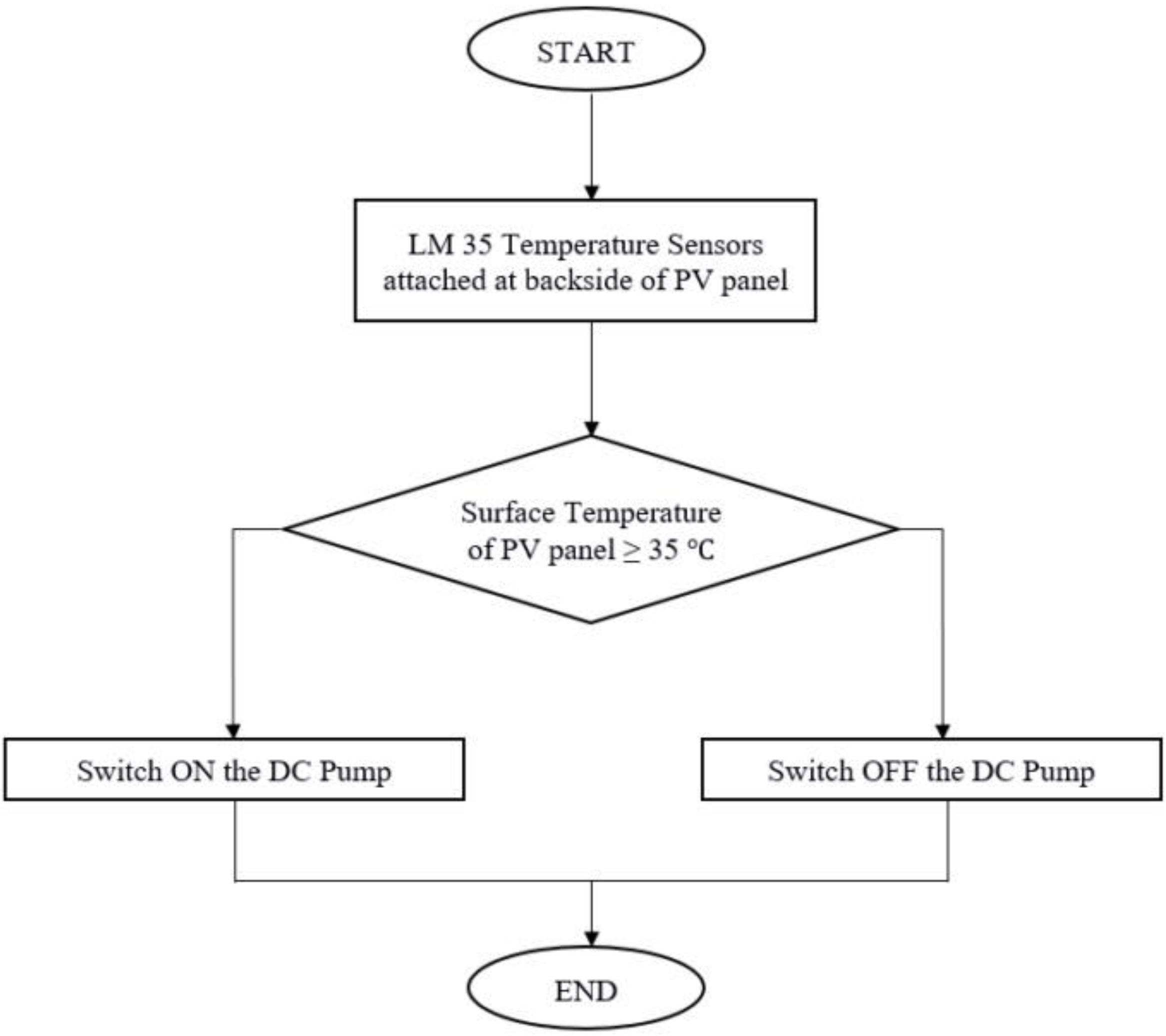

Fig. 18. Flow chart of controlled PV water cooling used [98]

Idan et al. [99] made a numerical and experimental study focused on using a temperature controlled PV water cooling system. They used in their study an Arduino platform, solenoid type of valve, relay, MAX6675 named amplifier, thermocouple of K-type, 12V transformer and a laptop.

They made a cooling cover without any absorbing material for the PV heat exchange process. In the numerical study they used ANSYS software for analyzing PV performance. Study results showed a 12.78% increase in PV electrical efficiency and showed that using temperature control system caused a 29.28% decrease in water consumption and rises the PV electrical efficiency up to stable range 15.37 – 15.38%. Hamada et al. [100] studied using three different shapes of absorber with the same length and diameter that were compared and tested in Cairo city located in Egypt in summer of 2021. They established their study using a fuzzy logic control system with ARMAX type of model. They used in their study a water tank, Rotameter, pump, Digital manometer, Data logger and a solar power meter. Using water flowrate equaled 3 L/min led to a Reduction in PV cell temperature equaled 3.8°C, 4.8°C and 3.6°C for absorbers B, C and A. Previous studies using different PV water cooling control systems shown in Table 2.

Table 2. Previous studies using different PV water cooling control systems

Authors	PV cooling control system	Type of study	Main results		
			Temperature reduction	**Increase in Power Output**	**Increase in Efficiency**
(Sahu et al. 2021) [77]	ON-OFF control type	Experimental	Reached a 40°C reduction PV maximum temperature in 5 to 7 minutes	----------------------	-------------------------
(Prasad et al. 2021) [78]	ON-OFF control type	Experimental	-----------------	----------------------	17 % increase in electrical efficiency
(Laseinde et al. 2021) [29]	ON-OFF control type	Numerical modelling	-----------------	-----------------------	16.65 % increase in electrical efficiency
(Kamarudin et al. 2021) [79]	ON-OFF control type	Experimental	------------------	----------------------	17.08% increase in electrical efficiency
(Etier et al. 2021) [80]	ON-OFF control type	Experimental	A 26 % Reduction in PV surface temperature	A 6.86 % increase in the power output	-----------------------
(Kadhim et al. 2021) [82]	ON-OFF control type	Experimental and mathematical model	-------------------	-----------------------	23.1% increase in electrical efficiency for spray cooling type and 16% for evaporative cooling type
(Hajjaj et al. 2019) [83]	ON-OFF control type	Experimental and mathematical model	------------------	----------------------	0.046%/°C increase in electrical efficiency
(Harahap et al. 2021) [85]	ON-OFF control type	Experimental	--------------------	13.56% increase in the power output	----------------------
(Nabil and Mansour. 2022) [86]	ON-OFF control type	Experimental	29.37% reduction in PV surface temperature	--------------------------	6.84% increase in electrical efficiency
(Abdullah et al. 2021) [87]	ON-OFF control type	Experimental	--------------------	-------------------------	39.81% for thermal efficiency, 11.69% for electrical efficiency and 51.4% for overall efficiency
(Yacoub et al. 2022) [89]	ON-OFF control type	Experimental	10.55% reduction in PV temperature and	-----------------------	1.4 increase in electrical efficiency value equaled 12.61% increase percentage.
(Alshibil et al. 2022) [90]	ON-OFF control type	Experimental with TRNSYS modelling	------------------	-----------------------	Thermal performance for ON-OFF control type is 6.1% more than

Authors	PV cooling control system	Type of study	Main results		
			Temperature reduction	Increase in Power Output	Increase in Efficiency
	and PID control type				PID control type and 14.5% more than PV systems without using daily water with optimum tilt angle equals 30◦ in Hungary
(Mohamed et al. 2022) [91]	Not mentioned	Experimental comparison study	-------------------	45.7% increasing in maximum power output	------------------------
(Kusuma et al. 2023) [92]	ON-OFF control system type	Experimental study	-------------------	Reducing power losses by 4% and increased the power output by 1.553 watts	------------------------
(Singh et al. 2022) [93]	Not mentioned	Experimental study of four PV cases	-------------------	------------------------	increase PV electrical efficiency up to 13.3% in this article
(Novak et al. 2023) [94]	ON-OFF control system	Experimental study	--------------------	-------------------------	An improvement of PV performance equals 14 %
(Wang et al. 2022) [95]	ON-OFF control system type	Experimental study	A reduction in the PV temperature by 15.3 %	A 14.4 % increasing in PV power output	----------------------
(Winardi et al. 2022) [96]	An ON-OFF control system type	Experimental study of three cases	8.79 ◦C and 8.69◦C temperature reduction for taking 35 ◦C and 30 ◦C temperature set point	-------------------------	----------------------
(Azmi et al. 2023) [97]	ON-OFF control system type	Experimental study	---------------------	---------------------	A 4.5% improve in PV efficiency compared to uncooled PV system.
(Yusoff et al. 2024) [98]	ON-OFF control system type	Experimental study	--------------------	A 4.07 Watt increase in PV power output	-------------------------
(Idan, Kadhom and Faraj, 2024) [94]	ON-OFF control system type	Experimental and numerical study	------------------	----------------------	Increased PV electrical efficiency by 12.78% and reduced water consumption by 29.28%
(Hamada *et al.*, 2024) [95]	Fuzzy logic controller with ARMAX model with three different in shape absorbers	Experimental study	Using a 3 L/min water flowrate Resulted in a 4.8, 3.8 and 3.6°C reduction in photovoltaic cell temperature.	-------------------------	-------------------------

5. Effect of Solar Tracking Systems on PV Performance

Scientists from all over the world are doing their best to find a good sources for replacing fossil fuel energy sources [101]. One of these solutions was PV solar systems which it can be easily established at any location without requiring a lot of space. A 1.7×10^{22} J of energy is supplied by the sun in 36 hours, however the total energy annually used all over the world is 4.6×10^{22} J that equals what the sun produces in one hour [102]. Solar energy is an amount of energy which is radiated from the sun towards the earth, averaged intensity of solar radiation on the surface of the earth is 1367 Watts per square meters and the solar energy global absorption was approximated to 1.8×10^{11} MW [101]. This amount of solar energy is enough to meet all human energy needs [103]. In Fig. 19. Global solar energy demands were showed compared to actually power output of solar power plants over the globe. It refers to that northern Africa region located in the red part of the global incident solar radiation map that receives from 1899 kWh/kWp to 2191 kWh/kWp of photovoltaic power potential.

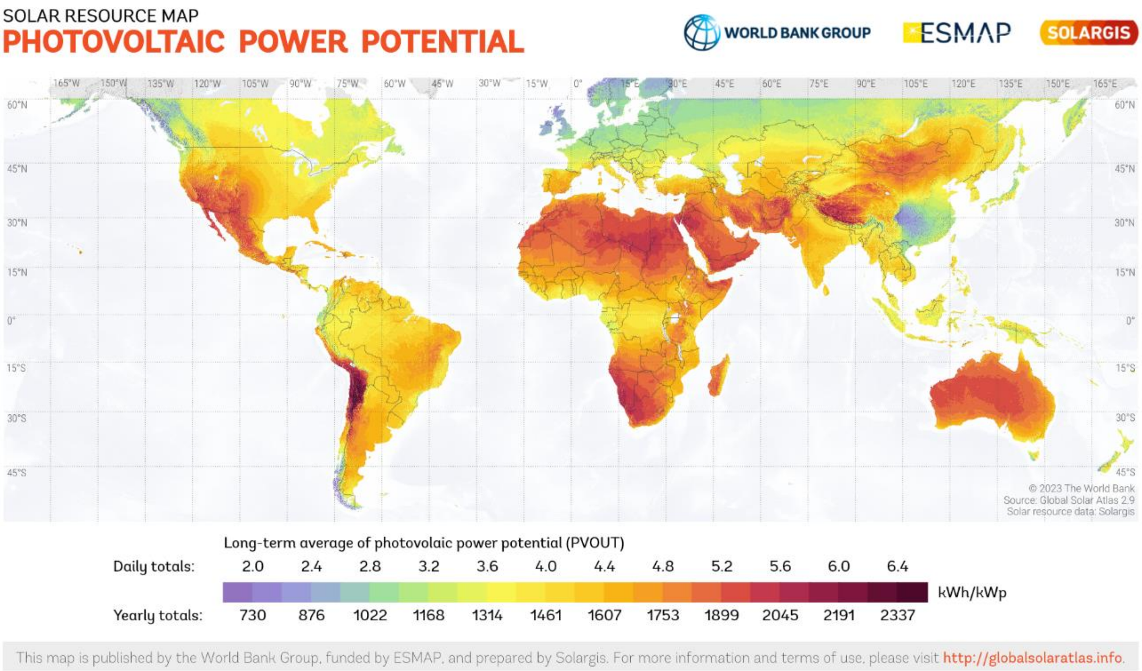

Fig. 19. Global direct normal incident solar radiation map, [104]

As sun moves from east towards west direction, tilt angle varies during the day. This made an attention to researchers to focus on how to make the PV panel track the sun movement for improving the solar radiation absorption. This section presents the previous studies on solar tracking systems for increasing the PV power output and the electrical efficiency. Awad et al. [105] used two axis solar tracking system for improving the PV efficiency. They found that the efficiency of the cell depends on the sun location and the intensity of the light. Their results showed that the solar tracking system improved the performance of the PV system by 25 % compared to the fixed one. Osman et al. [106] developed a PV tracking system to increase the PV electrical efficiency. They used the single and two axis solar tracking systems for eastern province location in Saudi Arabia. PID control was used with the PV tracking system in their study. They found that the energy consumed in two axis solar tracking system (3.9%) was more than the energy consumed in single axis solar tracking system (3.4%). In addition, the energy loss in two axis tracking system (13%) was higher compared with single axis tracking systems (7.8%). Their results proved that the energy output rate in single axis tracking system was increased by 18.73% compared by the fixed PV. Furthermore, the energy output rate in two axis tracking system was increased by 28.98% compared to the fixed PV. The close-loop feedback system was drawn and showed in Fig. 20.

Hariri et al. [107] established a single axis solar tracking system. They used azimuth angle control for tracking the solar radiation and made a comparison between utilizing azimuth, sensor solar tracking systems and fixed PV solar system. In their study, they focused on reaching the optimum azimuth angle based on the location altitude, time and date in addition to the embedded microcontroller. Azimuth based solar tracking system increased consumption of energy by 65 % compared with the sensor solar tracking system case. However, using sensor solar tracking system increased net energy production by 12.68% and 7.7% for the output energy compared to azimuth based single solar tracking system. Jain et al. [108], established a two axis solar tracking system with the aid of Arduino pro mini unit. They focused in their study on the solar PV parameters such as power output, voltage, cost and electrical efficiency. A comparison study was carried out between fixed, single and two axis solar tracking systems. For developing their solar tracking systems, they used two servo motors and light dependent resistors that sensed the solar radiation. Their results showed increasing in power rate production in single axis solar tracking system with 25% compared to the fixed solar PV. In addition, the power production rate was increased by 51% in two axis solar tracking system compared to the fixed solar PV.

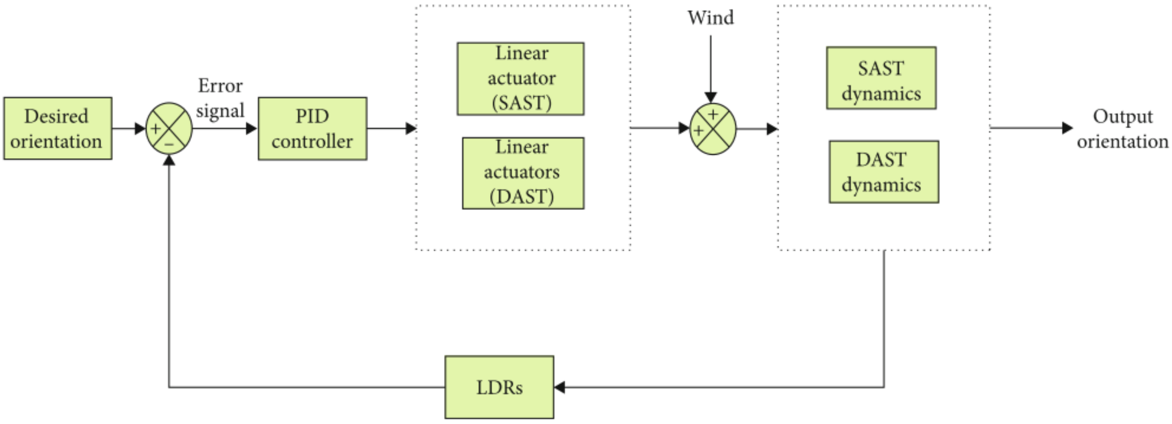

Fig. 20. The close-loop feedback system diagram [106]

Mohanapriya et al. [109] developed a two axis solar tracking system using the Arduino Uno and light dependent resistors sensors. A comparison study was conducted between fixed, single axis, and two axis solar tracking systems. They found from this study that the single axis solar tracking system could not track the maximum solar energy. In addition, the energy rate production was increased by (30-40) % in case of the two axis solar PV systems compared to the fixed PV panel system and increased by (6-7) % in case of the single axis solar tracking system compared to the fixed PV panel system. Mollahasanoglu et al. [110] made a comparison study between the fixed and the two axis solar tracking system. Their study was taken for three days which were cloudy. Their results showed that the averaged power output value for the first day increased by 3.17 watt using the two-axis solar tracking system compared with the fixed PV panel system, 2.9 watt for the second day, and 3.02 watt for the third day. Kyi and Taparugssanagorn. [111], used a wireless sensing system for remote operating the solar PV system. Zig Bee technology was used in their research work. They found that to reach the maximum power output, sun rays should be tracked. Therefore, they used a two-axis solar tracking system incorporated with an Arduino microcontroller, direct current motor, and circuit of H-bridge motor driver, to obtain the optimum solar PV tilt angle. Their study showed that the tilt angle was 7.5 degree in anticipation of the current value of time.

Fahad et al. [112] executed comparative study between three PV panel systems; the first one was a fixed PV panel system, the second was a single axis solar tracking system and the third one was two axis solar tracking system. Their results showed that the single axis solar tracking systems increased the energy output rate by (25 – 40 %), while the two axis solar tracking systems increased the PV energy output rate by (26 – 45%). The results indicate that the energy yield of single-axis and dual-axis trackers does not significantly differ from one another. When the influence of cloud cover is considered, the percentage variation in total incident energy over the course of a year comparing the single and two axis tracker mechanisms is determined to be approximately 3.44%, down from 3.96% when it is not. Ayoade et al. [113] concerned their study on using smart dual axis solar tracking systems. They made a comparison study between dual axis solar tracking systems, single axis tracking systems and fixed solar tracking systems. They used an Arduino microcontroller as a control unit for controlling the solar tracking system. The results of this study produced increasing in PV efficiency equals 42 % compared to fixed PV systems. Using dual axis solar tracking system produced 9838.35 W electrical power compared to 8326 W for single solar tracking system.

Sun et al. [114] established a single solar tracking system which is a horizontal bracket with adjusting tilt angle. They made their studies using a real time adaptive tracking algorism as illustrated in Fig. 21. Using real time adaptive tracking algorism increased PV electricity energy by 7.5% and 32.7% compared to conventional algorisms of tracking systems and fixed bracket PV systems.

Hadroug et al. [115] made a study in two stages; firstly, by using two axis solar tracking PV system. Secondly, it was a study based on using the concept of artificial intelligence as using technology of neuro fuzzy with an adaptive type of inference structure without using Light dependent resistor. Study results showed that using artificial intelligence technique improved PV performance and it increased PV efficiency. In addition to, using two axis solar tracking system increased PV efficiency by 24.44% compared to fixed PV solar system. Anshory et al. [116] established a two axis solar tracking system using ESP8266 as a microcontroller and light dependent resistors (LDRs) with the aid of using servo motors for PV panel tilt angle adjustment and Internet of things technology (IOT) for PV parameters remote monitoring and controlling. Study results showed that using two axis solar tracking system led to an average increase in PV efficiency, speed and accuracy equaled 65% compared to manually monitoring PV solar system. Previous studies which were focused on enhancing PV performance using various PV solar tracking systems are showed in the following table.

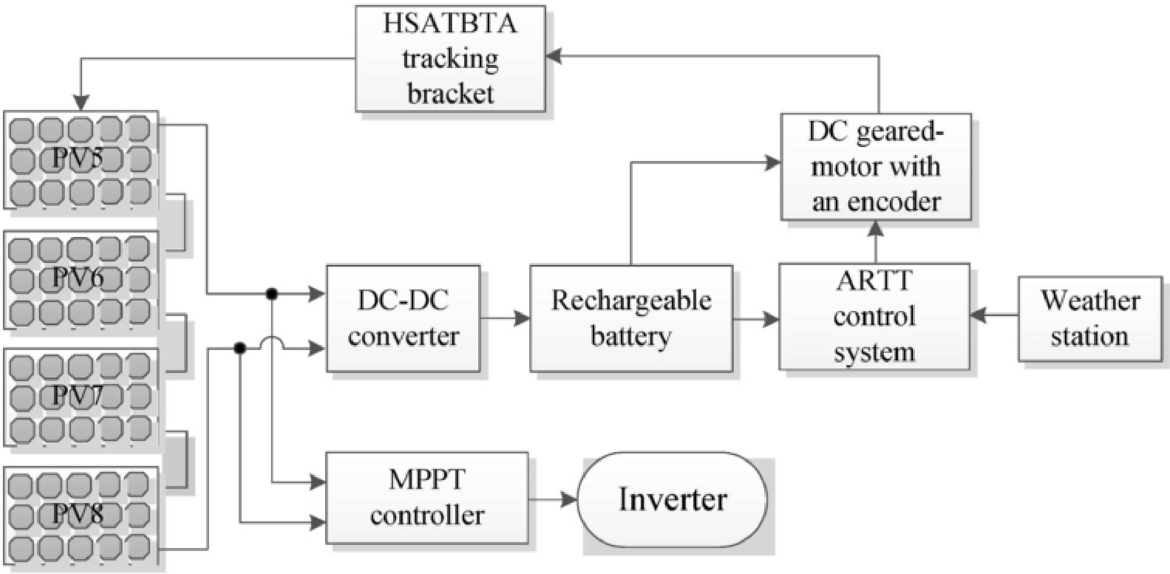

Fig. 21. Flowchart of adaptive real time tracking PV system used [114]

An LDR is a resistor that is operated by light. When incoming light strikes the circuit, the electrical resistance of the LDR decreases, and when there is no light source available, the resistance increases [117]. Unfortunately, LDRs have several serious drawbacks that can negatively impact solar tracking performance, such as light intensity saturation and inefficiency in low visibility situations. The potential to overcome the limits of LDRs is demonstrated by the use of the ultraviolet (UV) radiation recorded by UV sensors [118]. Jamroen et al. [118] studied the ultra violet (UV) rays sensing solar tracking system was used for obtaining the maximum PV panel power output because the use of light dependent resistors has a limitation during the cloudy weather. A comparison study was conducted between UV sensing solar tracking system and light dependent resistor (LDR) sensing solar tracking systems and fixed PV panel system. The results showed that the UV solar tracking systems increased the production of energy with 19.97% compared with the fixed PV panel systems and 11% compared with LDR solar tracking systems. The summary of previous studies on using different solar tracking systems shown in Table 3.

Table 3. The summary of previous studies on using different solar tracking systems

Author	Type of Solar tracking system	Type of study	Main results	
			Increase in output power	**Efficiency improvement**
(Awad et al. 2022) [105]	two axis solar tracking system	Experimental	--------------------------	25 % performance improvement
(Osman et al. 2022) [106]	Single solar tracking systems with PID control type two axis solar tracking systems with PID control type	Experimental	18.73% for single tracking system 28.98% for two axis tracking system	-------------------------- --
(Hariri et al. 2022) [107]	single axis solar tracking system with PID control system	Experimental	12.68% increasing in power production	-------------------------- --
(Jain et al. 2021) [108]	Single solar tracking system two axis solar tracking system	Experimental	25% for single solar tracking system 51% for two axis solar tracking system	-------------------------- -
(Mohanapriya et al. 2021) [109]	two axis solar tracking system	Experimental	(30-40) % increasing in energy rate compared to fixed PV system	-------------------------- -
(Mollahasanoglu et al. 2021) [110]	two axis solar tracking system	Experimental	3.17 watts compared to fixed PV system	-------------------------- -
(Kyi et al. 2020) [111]	two-axis solar tracking system	Experimental	-------------------------	Increased the energy efficiency by 5.29%.
(Fahad et al. 2019) [112]	Single solar tracking system two axis solar tracking system	Experimental	--------------------------	Single tracking systems increased the energy output rate by (25 – 40 %) Two axis tracking system increased the PV energy output rate by (26 – 45%)
(Jamroen et al. 2021) [118]	ultraviolet (UV) rays sensing solar tracking system	Experimental	increased the production of energy with 19.97% compared to fixed PV system and 11% compared to LDR solar tracking systems	-------------------------- -
(Ayoade et al. 2022) [113]	Dual axis solar tracking system	Experimental	-------------------------	Increased the PV efficiency by 42%.
(Sun et al. 2023) [114]	Single solar tracking with a real time adaptive tracking algorism and fixed PV system	Numerical	increased PV electricity energy by 7.5% compared to other algorisms and by 32.7% compared to fixed PV systems	-------------------------- --
(Hadroug et al. 2023) [115]	Two axis solar tracking, artificial intelligence technology using neuro fuzzy and adaptive structure	Experimental and numerical	-------------------------	improved efficiency and performance by 24.44%
(Anshory et al. 2024) [116]	Two axis solar tracking system	Experimental	-------------------------	Resulted an average increase in efficiency equaled 65%

6. Challenges of Utilizing PV Panel Solar System

Over the next five years, renewable power capacity increases will continue, with photovoltaic PV and wind representing a record 96% of the total as in most countries, their generating costs are lower than those of both fossil as well as non-fossil alternatives, and government policies continue to promote them [119]. By 2028, solar photovoltaic which may be utilized in several applications such as irrigation processes [120], and wind installations are expected to have more than doubled from 2022 levels, smashing records every step of the way to over 710 GW as illustrated in Fig. 22. [119].

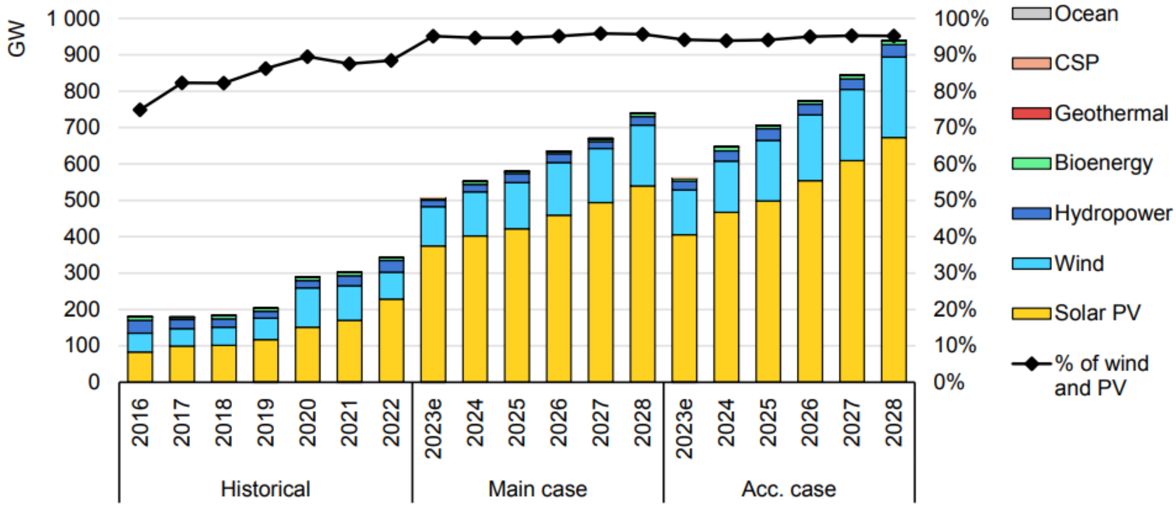

Fig. 22. Increases in the capacity of renewable electricity by technology and sector, 2016-2028 [119]

With a 25–30 year lifespan, solar waste may arise in the next years as a result of increased production of these panels [121]. Moreover, it is predicted that by 2030, 74.7 Mt of electronic waste will be produced worldwide. By the end of 2030, 8 Mt of Photovoltaic panels are expected to be wasted annually [122]-[124]. In addition to, eighty millions of tons by 2050 [124]. But the recycling procedures used for these devices now are insufficient and underutilized [124]. the quantity of CO2 emissions produced during the manufacture of a photovoltaic panel and the quantity produced during its recycling varied significantly, PV panels cause much less damage to the environment when they are recycled. Reusing materials can also be a cost-effective way to recover some rare natural resources [121]. According to Wang [125], the recycling process of photovoltaic panels is essential for environmental and financial reasons alike. He noted that solar energy can produce a substantial amount of waste materials. Materials used in PV modules can be recycled chemically and physically; recycling of electronics and PV modules is not the same [126]. According to Dias and Veit [127], recycling solar modules is crucial for lowering production costs and negative environmental effects. All three of these types of materials are included in c-Si, which is used in a large majority of solar modules on the market [126].

7. Discussion

In this article, previous studies was presented focusing on studying different ways for increasing PV efficiency using PV water cooling control systems and PV solar tracking systems. These studies proved that using control systems with PV water cooling systems enhances increasing PV electrical efficiency and increases PV maximum power output. Utilizing water cooling techniques for PV solar panel particularly in hot climates has been under studying by scholars and scientists. Therefore, many researchers have studied and established utilizing water cooling techniques as illustrated in the literature review. However, large solar parks such as Benban solar park had included an automated robotic cleaning system which was established on the water-cooling principle to protect large number of PV solar panels from dust and excess heat problems. This answer was added to the discussion section page.

From these studies it was found that using Arduino microcontroller as a controller is a well choice as Arduino is a perfect controller with low cost Arduino is cheap unit and easy to program and widely used in many applications such as smart home project mentioned in [128] and 5-DOF Manipulator project based on 3D Printing Technology which can be used for several industrial purposes as showed in [129]. Using water film cooling absorbs heat more than other methods, in addition to using water closed cycle enhances Rationalization of water usage. Previous studies on using PV solar tracking systems were also presented in this article that proved that using PV solar tracking systems produces more power output and higher electrical efficiency than conventional fixed PV solar systems. Using light dependent resistors LDRs provides a perfect way for tracking the solar rays that increases the solar rays absorbed in PV panels.

For the solar tracking mechanism to function, the sun's light must be released. As sensors, the LDRs measure the quantity of light that reaches the solar panels. Following that, the Arduino microcontroller receives data from the LDR, this then automatically modifies the motors to rectify the position of the solar panels, the resistive value of a particular resistor changes in response to a change in intensity, indicating that the LDR accurately responded to the design constraints of low cost, neutral polarity, ease of circuit interface, and high spectral sensitivity [113]. They specifically made use of light-dependent resistors (LDRs), which can detect visible light. Unfortunately, there are a number of serious drawbacks to LDRs (such as light intensity saturation and inefficiency in low visibility situations) that can negatively impact solar tracking performance [118]. Therefore, making use of the ultraviolet (UV) spectrum recorded by UV sensors shows promise in getting over LDR constraints [118].

PID controllers are frequently employed to control the temporal behavior of numerous varieties of dynamic plants [130]. PID is a method of control that uses three separate mathematical processes and adding up the outcomes to provide a control output to eliminate system mistakes. PID stands for proportional, integral and derivative terms. It is a mathematical phrase that controls output resulting from the interaction of these three terms [131]. The PID control system implemented such PID control systems utilizing Matlab and Arduino as the instruments for data collecting after applying an empirical technique to obtain the DC motor response system to find the best fit of proportional gain, integral gain, and derivative gain [132]. The motor that receives pulses from PWM to control the amount of incoming power moves as a result of the PID control's output [132]. The PID controller offers the best control dynamics, with minimal oscillations, quick response (low rise time), zero steady-state error, and increased stability. Eliminating overshoot and oscillations in the system's output response requires the use of a derivative gain element to be added to the PI controller. The PID controller's ability to be employed with higher-order processes, such as multiple energy storage systems, is one of its primary benefits [131].

In comparison to other controllers, the fuzzy controller, which enables the operation of an electrical system with expert decisions, is best suited for the human decision-making system. Furthermore, reducing the uncertain effects on the system control is possible by employing the fuzzy controller to control the nonlinear system [131].

Single solar tracking system can provide a 20% output power compared to fixed PV solar panel [133]. In considering cost parameter in comparing single axis tracking, dual axis tracking and fixed axis solar systems, when utilizing a dual axis tracker, we may maximize power production by approximately 40%. This can be significantly higher if the tracker is being used for a large application in industry [134]. While tracking system and PV solar panel monitoring technologies are more costly and difficult to implement than fixed ones, they can become cost-effective when used to control several modules at the same time and can be applied to industrial applications because they can provide more power year-round [134]. So, for both the tracker system and the static system, we need to figure out the price per watt installed and delivered. That question can also be posed in the opposite direction [135]. Despite having a better power effectiveness than fixed solar panels, solar tracking systems are not very popular because of their costly initial investment and ongoing maintenance expenses [136].

From these studied we concluded that using control systems with PV water cooling systems and using PV solar tracking systems with a more cost-effective way will enhance the benefits of using solar energy and reduces the need of using conventional energy sources that have harmful effect on human health and environment. Utilizing water cooling technique is suitable for our country as the water is available with low cost. In addition to closed lope PV water cooling systems didn't lose significant amount of water by evaporation so it didn't require large quantity of makeup feed water. Therefore, is a suitable way for enhancing PV electrical performance in hot climate countries with the availability of water. However, other cooling techniques such as phase change material and air-based cooling methods can be utilized in regions with scarce water resources problem.

8. Conclusion

Using PV panel cooling techniques is a good solution for the overheating problem occurring due to the increase in the PV panel temperature. Water based cooling system is the best choice for decreasing the PV panel temperature [32], [37]. With considering the availability and low-cost parameters. In addition to having a large heating capacity that can absorb large amounts of excess heat from the PV panel. Therefore, establishing water cooling systems in large solar parks as Benban solar park that contains large number of PV panels requires large number of workers who would operate and maintains water pumps for all solar panels so it is important to utilize a temperature control technique for the PV water cooling system to improve the performance and save the time and human effort in addition to ensuring operating the solar system at the desired standard operating temperature. scientists developed different control systems for cooling the PV modules based on the water utilizing microcontrollers such as Arduino unit as it is cheap and easy in programming and controlling PV water cooling system parameters such as PV temperature, power output and water flowrate. Utilizing water cooling, temperature-controlled PV water cooling system enhances PV electrical performance. However, these techniques face cooling water evaporation particularly in front surface water cooling systems which provides the need of continuous feeding of makeup water for the replenishment of evaporated water. Scholars found that tilt angle has a great influence on the PV power output, so they made different experiments and investigations on controlling and optimizing the PV tilt angle. Solar tracking systems were developed for maximizing the incident solar irradiation for producing the maximum electrical output energy. Two axis solar tracking systems produce more power output rates than the single axis tracking systems compared to the fixed PV panel systems while it consumes more electricity for motors operation and requires an additional cost compared to single axis tracking and fixed axis PV solar systems. Water cooling, temperature-controlled water cooling and solar tracking systems made PV solar panels a perfect solution for conventional hydrocarbon energy sources that harms human health and environment.

9. Recommendations and Future Works

From the presented review, it is recommended to use the PV water cooling system which controlled by ON-OFF and PID types because it increases the PV efficiency with low power costs. Furthermore, using Arduino unit is more efficient as it is easier in programming and cheaper compared with other microcontrollers. It is also recommended to use two axis solar tracking system because it increases the PV electrical efficiency and performance compared to the fixed PV panels. Using control systems such as PID control in two axis solar tracking systems is desired to reach the best optimum angles for the PV panel. Also, light dependent resistors (LDR) and ultraviolet (UV) sensors can be used in two axis solar tracking systems which produces an efficient sensing of solar radiation variation during day. Intelligent control such as fuzzy logic and neural networks and robust control such as H-infinity can be tried and investigated for improving the PV performance.

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