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EXPERIMENTAL INVESTIGATION OF A MOBILE PV WATER PUMPING SYSTEM

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Abstract

Solar water pumping system has several advantages as alternative energy source of energy instead of diesel and electric generators. It is Eco-friendly, simple, easy to install, and available in each site location. The main components of the PV water pumping system are PV modules, inverter, control, metallic structure, and submersible or surface water pump. The main parameters affecting the performance of the solar water pumping system are the PV module tilt angle and orientation as they affect the solar radiation falling, electric power output and amount of daily water produced. The experimental work is designed, installed and tested in the solar energy department, Engineering and Renewable Energy Research Institute, National Research Centre, Dokki, Giza, Egypt. In the current study the system performance in the four seasons at different tilt angle and orientations is evaluated. The solar radiation falling on the PV modules and the electric power produced are measured for different tilt angles and orientations in the four seasons. Also the daily water produced for different tilt angles and orientations in the four seasons is estimated. It is found that for south facing and tilt angles 0, 10, 40, and 80, the maximum value of daily water produced is occured in Summer while the minimum value is occoured in winter. It is found also that the daily water produced, m^3 is affected by both tilt angles and azimuth angles in each seasons, the maximum value of the daily water produced, m^3 in summer with tilt angle equal 10 and azimuth angle equal 0 while the maximum value attained in winter with tilt angle equal 60 and azimuth angle equal 0. The maximum value of summer, autumn, winter, and spring were 32 m^3, 27.25 m^3, 27.25 m^3, 27.50 m^3 for south facing and tilt angles 10, 40, 60, 40 respectively.

Keywords: experimental investigation, solar, water pumping system, tilt angle, orientation, PV sizing.

التحقيق العملى لنظام ضخ مياه متنقل يعمل بالخلايا الشمسية

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الملخص العربي

يتميز نظام ضخ المياه بالطاقة الشمسية بالعديد من المزايا كمصدر بديل للطاقة بدلاً من مولدات الديزل والكهرباء، كما يعتبر صديق للبيئة ، بسيط، سهل الانشاء ومتواجد فى موقع الانشاء. والمكونات الرئيسية لنظام ضخ المياه بالطاقة الشمسية هى وحدات الخلايا الشمسية، ومغير التيار ووحدة التحكم والهيكل المعدني، ومضخة المياه الغاطسة أو السطحية، أن أهم العوامل التي تؤثر على أداء نظام ضخ المياه بالطاقة الشمسية هى زاوية الميل والاتجاه للخلايا الشمسية والتى تؤثر على كمية الطاقة الشمسية الساقطة على سطح الخلايا وكذلك كمية الطاقة الكهربية المنتجة من الخلايا ومن ثم كمية المياه التى يتم ضخها يوميا باستخدام الطاقة الشمسية.

تم تصميم وانشاء واختبار نظام ضخ المياه بالطاقة الشمسية بقسم الطاقة الشمسية بالمركز القومى للبحوث بالدقى – جيزة – مصر. في الدراسة الحالية تم تقييم أداء النظام في الفصول الأربعة بزوايا ميل واتجاه مختلفة حيث تم قياس كلا من الإشعاع الشمسي الساقط على الخلايا الشمسية والطاقة الكهربائية المنتجة لزوايا ميل واتجاهات مختلفة في الفصول الأربعة، كما تم تقدير كمية المياه اليومية المنتجة في كل حالة، وقد وجد أنه بالنسبة للزوايا المواجهة للجنوب وزوايا ميل 80, 40, 10, 0 أن القيمة القصوى للمياه اليومية المنتجة تحدث في الصيف بينما وجد أن أقل قيمة تحدث في الشتاء، ووجد أيضاً أن المياه المنتجة يومياً تأثرت بشكل ملحوظ لزوايا الميل والاتجاه في كل فصل من فصول السنة حيث وجد أن القيمة القصوى للمياه اليومية المنتجة، م٣ في الصيف كانت بزوايا ميل تساوي ١٠ وزاوية اتجاه (سمت) تساوي 0 (أي مواجهة للجنوب) بينما القيمة القصوى تتحقق في الشتاء بزاوية ميل تساوي ٦٠وزاوية سمت تساوي 0 وكانت أقصى قيم للصيف والخريف والشتاء والربيع هى ٣٢م٣، ٢٧,٢٥م٣، ٢٧,٢٥م٣، ٢٧,٥٠م٣ في حالة اتجاه الجنوب (زاوية سمت تساوي 0) وزاويا الميل 40, 60, 40, 10 على التوالي.

متنقل ، زوايا الميل والاتجاه تصميم الخلايا الشمسية الكلمات المفتاحية : التحقيق العملى ، نظام ضخ مياه،

1. INTRODUCTION

Water pumping worldwide is generally dependent on conventional electricity or diesel generated electricity. Solar water pumping minimizes the dependence on diesel, gas or coal based electricity. Solar pumping systems are environment friendly and require low maintenance with no fuel cost [1]. Keeping in view the shortage of grid electricity in rural and remote areas in most parts of world, PV pumping is one of the most promising applications of solar energy. A properly designed PV system results in significant long-term cost savings as compared to conventional pumping systems. In addition, tanks can be used for water storage in place of requirement of batteries for electricity storage [2]. Water is pumped during day and stored in tanks, for use during day time, night or under cloudy conditions. The water tank acts as storage and generally battery is not used for storage of PV electricity; however, for specific reliable requirements it can be used. Solar water pumping is based on PV technology that converts sunlight into electricity to pump water. The PV panels are connected to a motor (DC or AC) which converts electrical energy supplied by the PV panel into mechanical energy which is converted to hydraulic energy by the pump. The capacity of a solar pumping system to pump water is a function of three main variables: pressure, flow, and power to the pump [3]. PV system of a solar pump consists of PV modules connected in series and parallel combination as per motor voltage requirement. The electric energy produced from a PV module is effected by amount of solar radiation falling on the PV module surface area, the module surface temperature, shading, and accumulated dust on the PV surface. Recently, The PV module is manufactured to operate at maximum power point tracking (MPPT). A typical solar pump draws water from the well or surface water source to storage tanks or users directly [4]. Solar pump choice is determined by the site condition, flow required and nature or type of water resource (surface or underground). Thus, there are two major types of solar pumps depending on the location of water source; Submersible pump and Surface pump [5]. The most commonly used submersible pumps are centrifugal pumps and positive displacement pumps [6]. The principal operation of centrifugal pumps is the rotation of blades known as impellers which are arranged in stages at high speed, water is thrown radially by centrifugal force [6]. Centrifugal pumps are more efficient but its efficiency decreases with the decrease in speeds, thus at low insolation the pump works at low efficiency [1]**.** It should be noted that centrifugal pumps allows the pressure increase by increasing the number of stages, each stage of a centrifugal pump has a power consumed during operation. Positive displacement pumps are more efficient where there is large heads and low flow requirements. Surface pumps are commonly applicable in surface water sources such as ponds, shallow wells, and streams, the water to be pumped should not be more than 7 meters below ground level or pump inlet as 9 m suction lift. The performance of solar pump depends on the water requirement, size of water storage tank, head (m) by which water has to be lifted, water to be pumped (m^3), PV array virtual energy (kWh), Energy at pump (kWh), pump efficiency (%), and system efficiency (%) and diurnal variation in pump pressure due to change in irradiance and pressure compensation . The performance of solar water pumping system depends on the following parameters; Solar radiation availability at the location; Total Dynamic Head (TDH); Flow rate of water; Total quantity of water requirement; and Hydraulic energy: potential energy required in raising the water to discharge level. The main objective of the current study is to provide an experimental investigation of the performance of solar water pumping system at different tilt angles and orientations in Cairo, Egypt.

A study was done to investigate the performance of PV solar water pumping system with total dynamic head 35 m and daily water demand 3 m^3. It is found that that pumping system was most efficient in terms of cost-effectiveness, amount of daily work done and water flow [7]. Most of the world’s current electricity is produced by the combustion of fossil fuels that causes lots of crises due to their high demands and high prices, also the fuel security transportation. In addition to pumping a lot of pollutants to the atmosphere that negatively affect the human body and spread a lot of dieses like bronchial asthma [8]. On the other hand, utilizing green energy, environmentally friendly renewable energy sources can positively contributed in mitigation of greenhouse gas (GHG) emissions and consequently improve the climate [9]. Because of these, the governmental and private sectors including consumers are using the potential of utilizing the renewable energy sources like solar, wind, biomass, wind, hydroelectric, and geothermal,…etc. It has a good advantage that are abundant, durable, affordable and a clean source of energy but still it initial cost is relatively high [10]. Due to the fast growth of renewable energy technology, the power generation from solar energy is consider in the focus of the consumer Closas and Rap[12] presented from the point of view of the sustainability, policies, and restrictions in the solar pumping of groundwater for irrigation, is to highlight the importance of monitoring the groundwater abstraction, targeting at subsidies, monitoring of resource use and improving knowledge. Based on that, if not control that issue, it could lead to further depletion of groundwater, which could affect the sustainability of this technology and dependent livelihoods in the future. Maurya et al., [13] discussed the limitations and scope of PV solar water pumping system. Based on that, there are several advantages such as low maintenance, long service life, do not require fuel, didn't make pollution and is easy to install. Also, as solar energy is used, as an energy source, the periods of maximum demand for water match with the periods of maximum solar radiation. Sontake and Kalamkar [14] presented the general classification of solar PV water pumping system, historical background of solar pumping systems, the various efforts undertaken by researchers working on the different aspects of solar PV water pumping and the present status of research on the topic. They reviewed maximum power point tracking system, different types of pumps and motors and rating of photovoltaic panel, which affect the performance, efficiency and economy of the solar PV water pumping system. It is concluded that the PV pumping system is more economic than diesel powered systems. Several researches, cited that PV systems for irrigation have the advantage of practically no maintenance when compared to manual pumps or internal combustion, are easy to install and do not contaminate the environment. Rawat et al., [15] reviewed modeling, design methodology and size optimization of PV based water pumping, standalone and grid connected system. In this paper, a comprehensive review of a comprehensive designing process of solar PV water pumping system, standalone PV system and grid connected PV system was presented. Abdelghani H. A. and Gouda E. A., [16] theoretically and experimentally studied the performance of PV Pumping System (PVPS). They found that there was a good agreement between the experimental measurements and the simulation. The error found between the measured and the calculated monthly flow rate and was less than 5%. It is found that the higher the temperature the lower of the quantity of the output water that reflected the importance of the cooling system for the PV modules. They concluded also that by using MPPT technique, the system performance is improved. Due to using MPPT, their proposed system efficiency is increased by 1.2% over the conventional one.

2. Design of solar water pumping system

The solar water pumping system was designed to allow the metallic frame holding the PV modules to be movable to study the system performance with different tilt angles and orientation. The metallic frame consisted of hydraulic system (DC motor, oil tank, hydraulic pistons, piping and control system. The system design is shown in Fig. 1 and Fig.2. Based on the design presented in Fig. 1 and Fig. 2, the experimental part was proceeded.

2.1. Experimental set up

The experimental setup was carried out in National Research Center, Dokki, Giza, Egypt. After preparation of all required raw materials (Iron sheets, metallic U, T, and L sections with different thickness and lengths, Wheels, Hydraulic system including oil, pistons, piping, connections, DC pumps, PV system including PV modules, pumps, inverter, charger controller, batteries, wiring system, and finally the controlled hydraulic arms that responsible to operate the whole system movement under different tilt angles and orientation). The manufacturing process was proceeded according to the system design and the final shape of the mobile PV water pumping system is shown in Fig. 3.

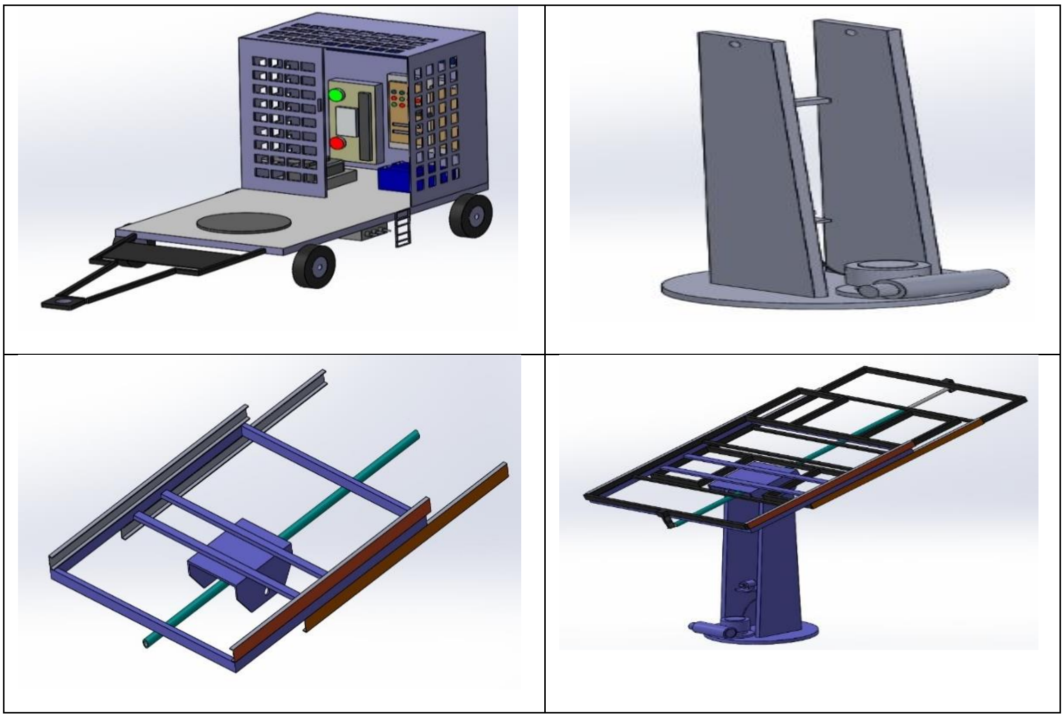

Fig. 1 Metallic frame design steps of the mobile PV water pumping system

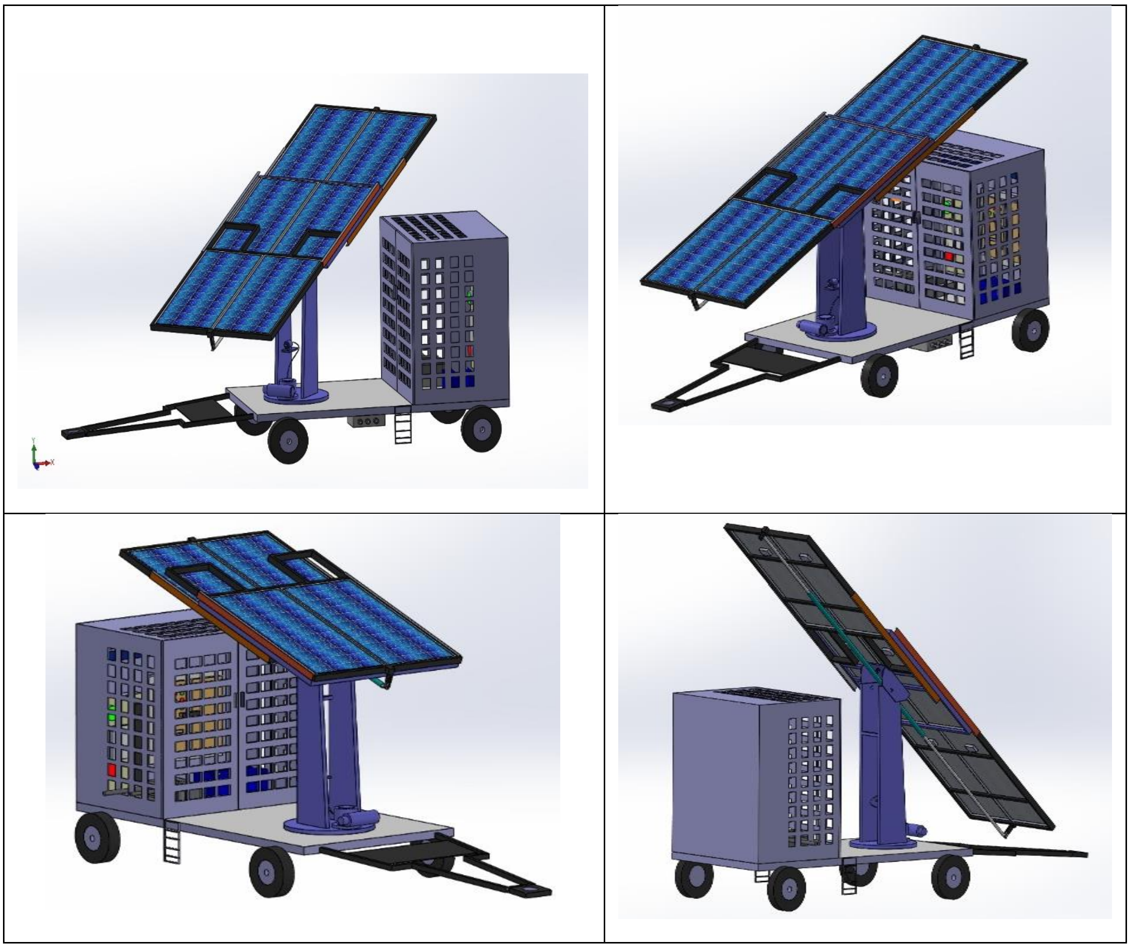

Fig. 2 PV module positions of the mobile PV water pumping system

The system equipment like water pump with suction and delivery hoses, inverter, and batteries are installed in the car frontal cabin as shown in Fig. 4.

Fig. 3 Final View of the mobile solar water pumping system

Fig. 4 Internal system components of the mobile solar water pumping system

Several devices were used to measure the different parameter in the solar water pumping system such as: **Multimeter**, to measure electrical voltage, current (amperage), resistance, and other values, **Solar Power meter** to measure the solar radiation, **Flowmeter (**Rotary vane wheel dry-dial water meter is used for measuring the volume of pumped irrigation water passing through the pipeline, and **Thermocouple** to measure the ambient temperature and it was calibrated in the range of 0-150 °C at a precision of 0.5 °C.

3. RESULTS AND DISCUSSION

The main purpose of the experimental work is to study the optimum outputs from the exploitation of solar radiation aiming to harvesting maximum water quantity. Two important factors to achieve the research target are the tilt angles and orientation of the solar panels according to location of the pumping system. Azimuth and Tilt angles were the orientation angles that considered, the performance of their impacts on the outputs of solar pumping system during the four seasons is studied. For examining outputs of the system under study, several factors were measured namely; solar radiation, ambient temperature, electric current and voltage to calculate the electric power output from solar panel, and daily water quantity collected. The experimental data were analyzed in the forms of figures to present the effect of tilt angles and orientation for the solar radiation falling on the PV panels, electric energy produced and amount of daily accumulated water pumped in the four seasons.

3.1. Effect of tilt angles and orientation in Summer Season

The relationship between solar radiation falling on the PV modules and time with various tilt angles and orientation is shown in Fig. 5 and Fig. 6. Figure 5 represents the relation between solar radiation (W/m^2) and time (hours) with fixed Azimuth angle and different tilt angles in Summer Season. It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules are for tilt angles equal 10, 0, 40, 60, and 80 respectively. Based on the results observed from Fig. 5, the maximum recorded solar radiation values are corresponding to tilt angle equal 10 and Azimuth angle equal 0. While Fig. 6 represents the values of solar radiation for a tilt angle equal 10 and different azimuth angles. It is found that the solar radiation values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

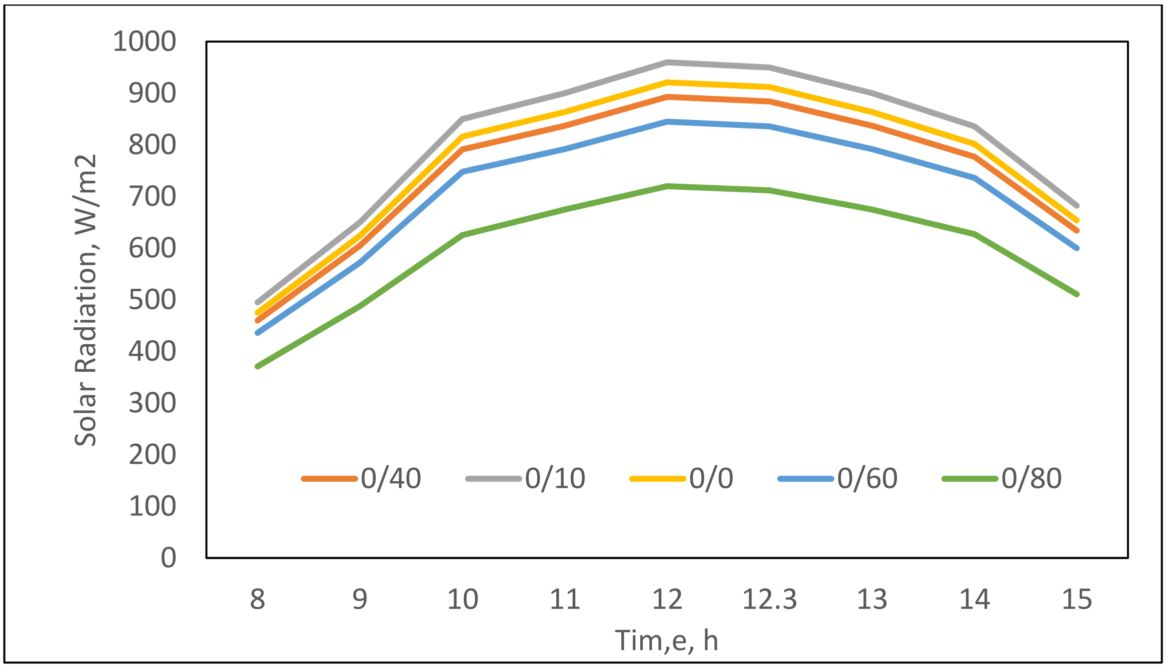

Fig. 5 Relation between solar radiation (W/m^2) and time (hours) with fixed Azimuth angle and different tilt angles in Summer Season

The relationship between electric power produced from the PV modules and time with various tilt angles and orientation is shown in Fig. 7 and Fig. 8. Figure 7 represents the relation between electric power produced from the PV modules (W) and time (hours) with fixed Azimuth angle and different tilt angles in Summer Season. It is found that for fixed azimuth angle (South facing), the higher values of electric power produced from the PV modules are for tilt angles equal 10, 0, 40, 60, and 80 respectively. Based on the results observed from Fig. 7, the maximum recorded electric power values are corresponding to tilt angle equal 10 and Azimuth angle equal 0. While Fig. 8 represents the values of electric power produced from the PV modules for a tilt angle equal 10 and different azimuth angles. It is found that the electric power values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

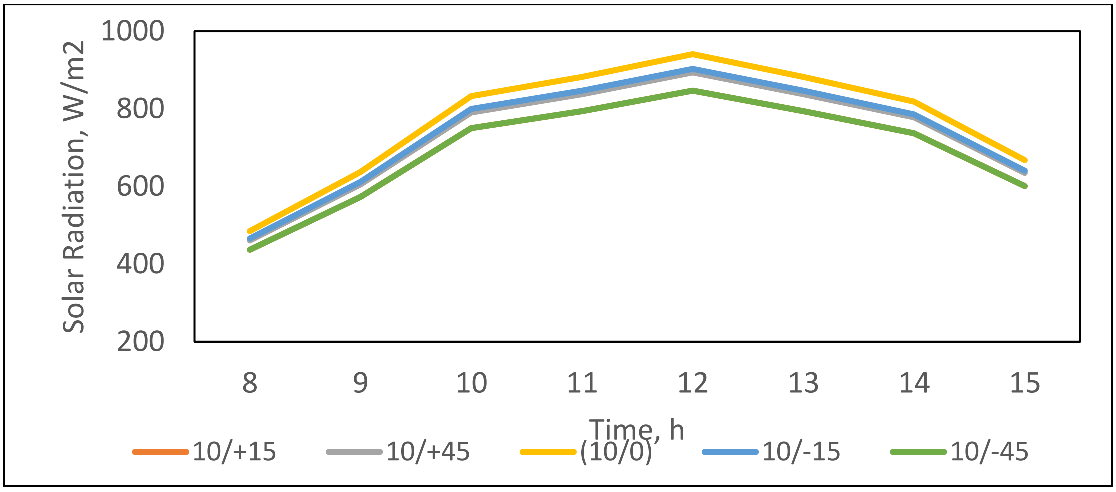

Fig. 6 Relation between solar radiation (W/m2) and time (hours) with fixed tilt angle and different Azimuth angles in Summer Season

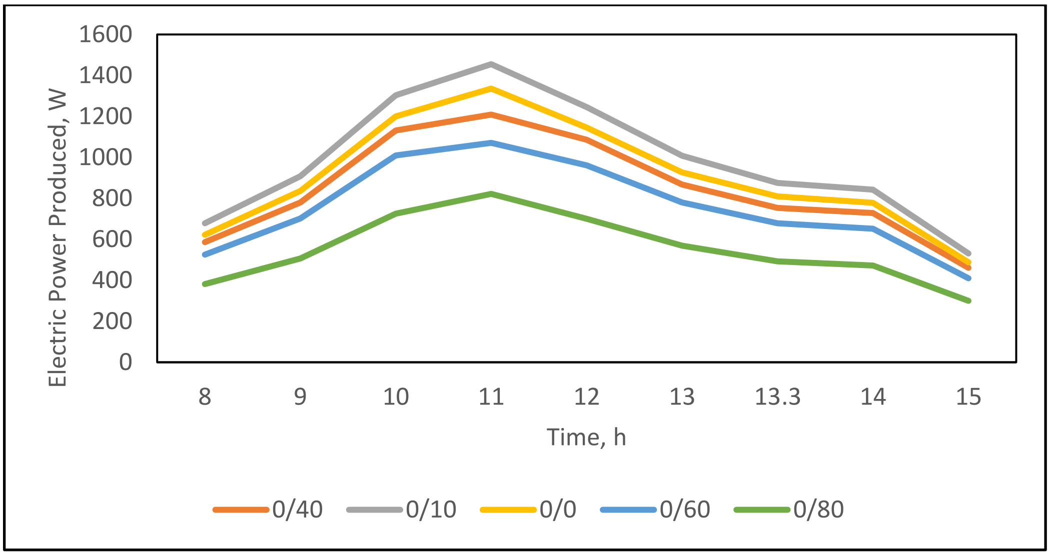

Fig. 7 Relation between electric power produced, W and time (hours) with fixed Azimuth angle and different tilt angles in Summer Season

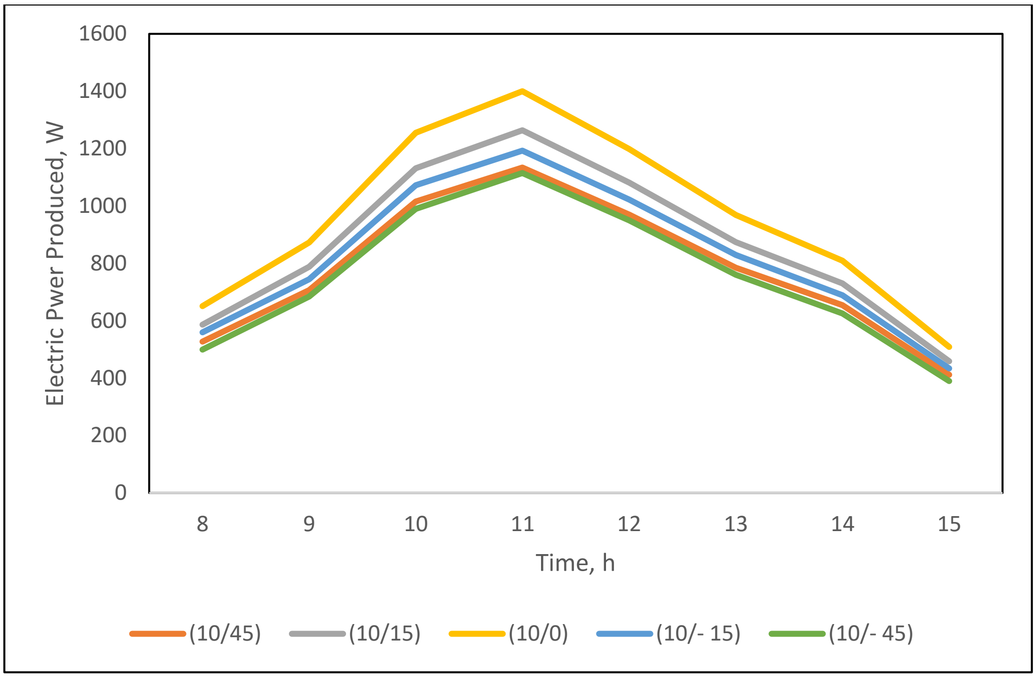

Fig. 8 Relation between electric power produced, W and time (hours) with fixed tilt angle and different Azimuth angles in Summer Season

Figure 9 describes the relation between daily water produced (m^3) with fixed azimuth angle (facing south) and different tilt angles. The results showed that the daily water produced are 29 m^3, 32 m^3, 28 m^3, 26 m^3, and 22 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 10 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80. While Fig. 10 represents the values of daily water produced based on its maximum value and different orientations either towards east or west direction.

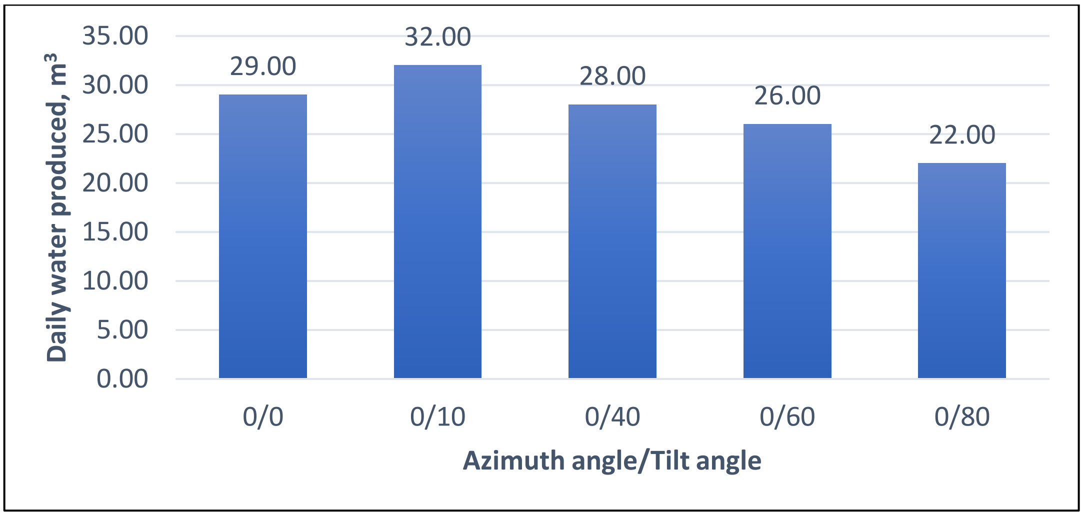

Fig. 9 Relation between the daily water produced, m3 with fixed tilt angle and different azimuth angles in Summer Season

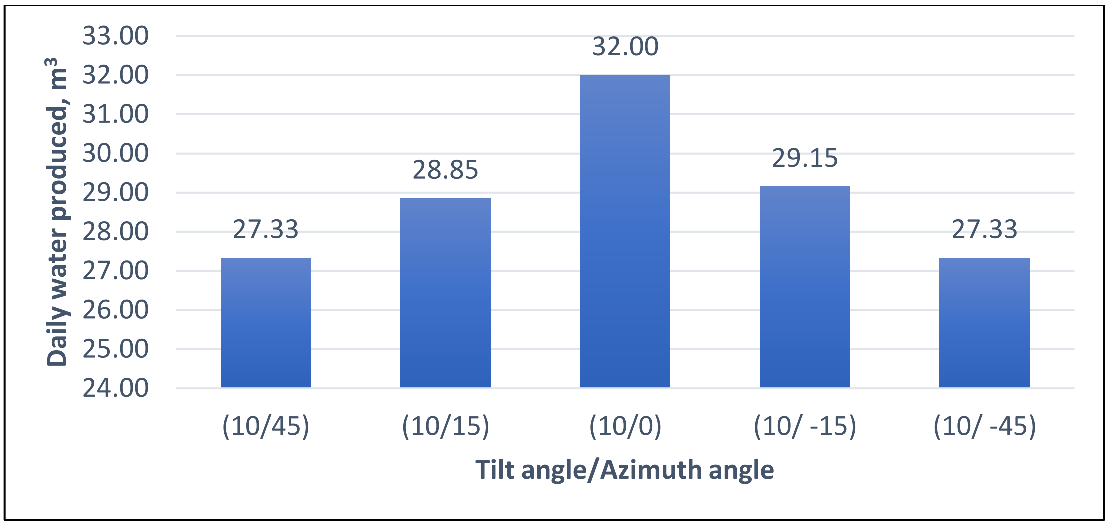

Fig. 10 Relation between the daily water produced, m3 with fixed azimuth angle and different tilt angles in Summer Season

3.2. Effect of tilt angles and orientation in Autumn Season

The relationship between solar radiation falling on the PV modules and time with various tilt angles and orientation is shown in Fig. 11 and Fig. 12. Figure 11 represents the relation between solar radiation (W/m^2) and time (hours) with fixed Azimuth angle and different tilt angles in Autumn Season. It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules are for tilt angles equal 40, 10, 0, 60, and 80 respectively. Based on the results observed from Fig. 11, the maximum recorded solar radiation values corresponding to tilt angle are equal 40 and Azimuth angle equal 0. While Fig. 12 represents the values of solar radiation for a tilt angle equal 40 and different azimuth angles. It is found that the solar radiation values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

The relationship between electric power produced from the PV modules and time with various tilt angles and orientation is shown in Fig. 13 and Fig. 14. Figure 13 represents the relation between electric power produced from the PV modules (W) and time (hours) with fixed Azimuth angle and different tilt angles in Autumn Season. It is found that for fixed azimuth angle (South facing), the higher values of electric power produced from the PV modules are for tilt angles equal 40, 10, 0, 60, and 80 respectively.

Based on the results observed from Fig. 14, the maximum recorded electric power values are corresponding to tilt angle equal 40 and Azimuth angle equal 0. While Fig. 15 represents the values of electric power produced from the PV modules for a tilt angle equal 40 and different azimuth angles. It is found that the electric power values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

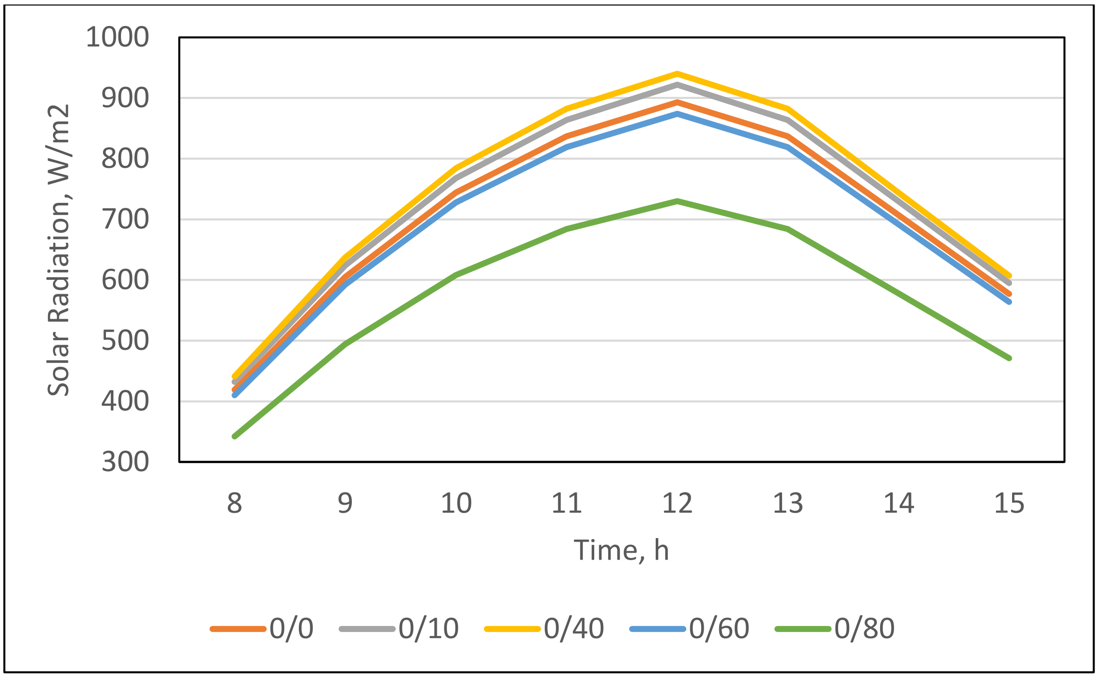

Figure 11 Relation between solar radiation (W/m2) and time (hours) with fixed Azimuth angle and different tilt angles in Autumn Season

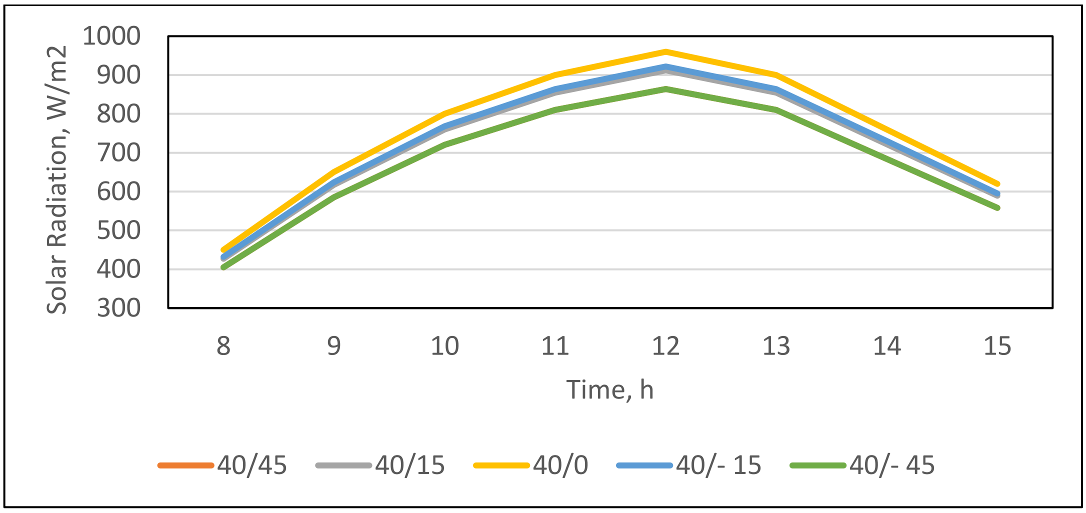

Figure 12 Relation between solar radiation (W/m2) and time (hours) with fixed tilt angle and different Azimuth angles in Autumn Season

Figure 15 describes the relation between daily water produced (m^3) with fixed azimuth angle (facing south) and different tilt angles. The results showed that the daily water produced are 23.6 m^3, 25.22 m^3, 27.25 m^3, 24.57 m^3, and 20.52 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 40 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80. While Fig. 16 represents the values of daily water produced based on its maximum value (azimuth angle equal 0 and tilt angle equal 40) and different orientations either towards east or west direction.

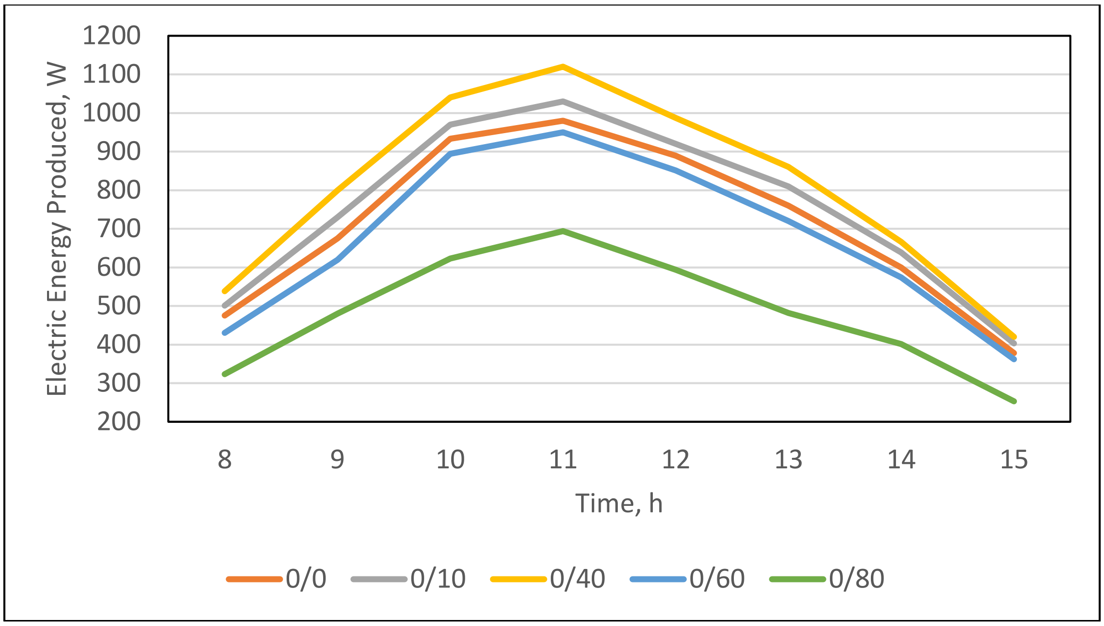

Figure 13 Relation between electric power produced, W and time (hours) with fixed Azimuth angle and different tilt angles in Autumn Season

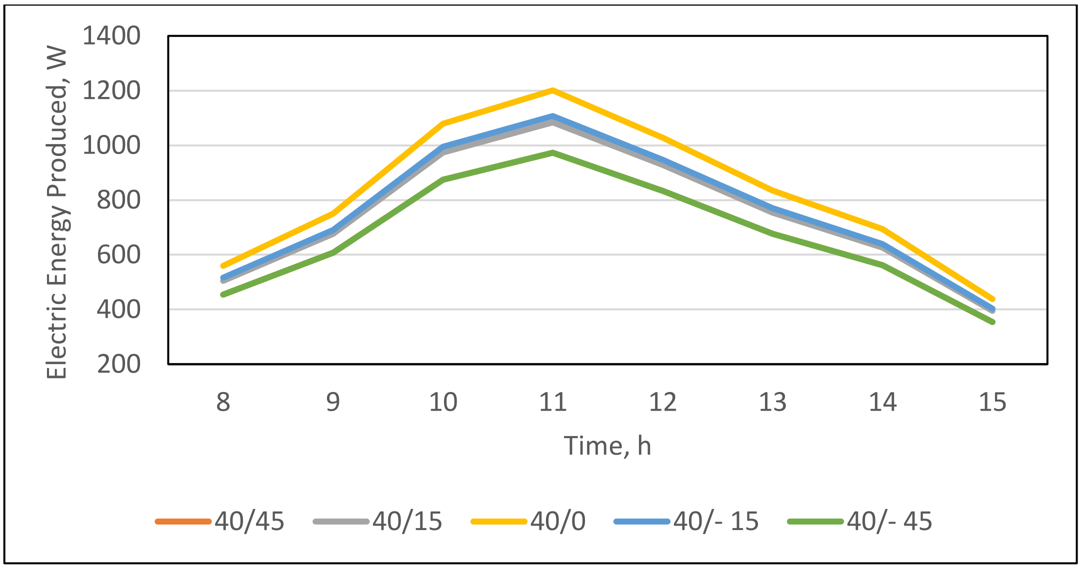

Fig. 14 Relation between Power (W) and time (h) with fixed tilt angles and different Azimuth angles in Autumn Season

3.3. Effect of tilt angles and orientation in Winter Season

The relationship between solar radiation falling on the PV modules and time with various tilt angles and orientation is shown in Fig. 17 and Fig. 18. Figure 17 represents the relation between solar radiation (W/m^2) and time (hours) with fixed Azimuth angle and different tilt angles in Winter Season. It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules are for tilt angles equal 40, 60, 80, 10, and 0 respectively. Based on the results observed from Fig. 17, the maximum recorded solar radiation values corresponding to tilt angle are equal 40 and Azimuth angle equal 0. While Fig. 18 represents the values of solar radiation for a tilt angle equal 40 and different azimuth angles. It is found that the solar radiation values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

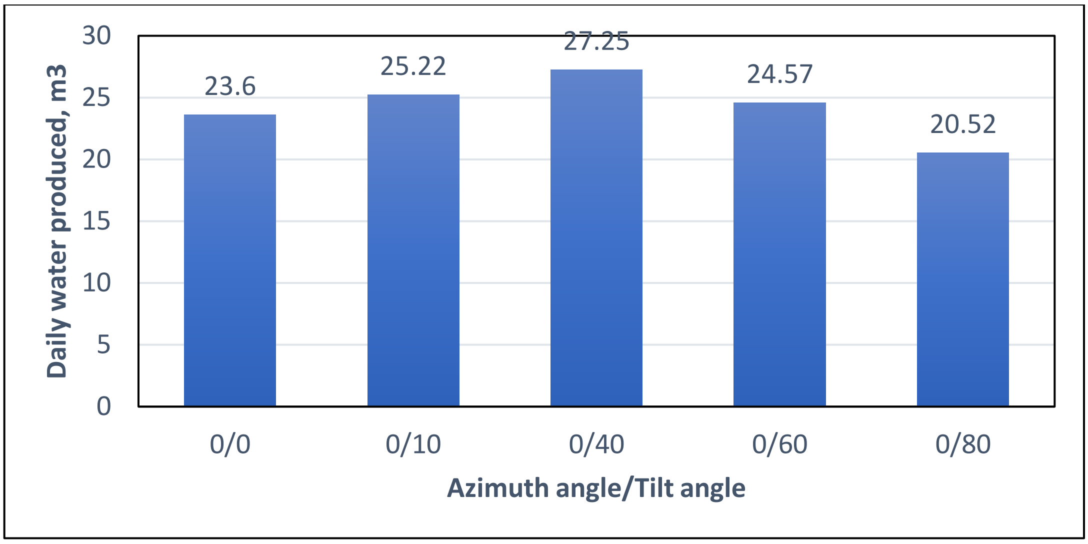

Fig. 15 Relation between the daily water produced, m3 with fixed azimuth angle and different tilt angles in Autumn Season

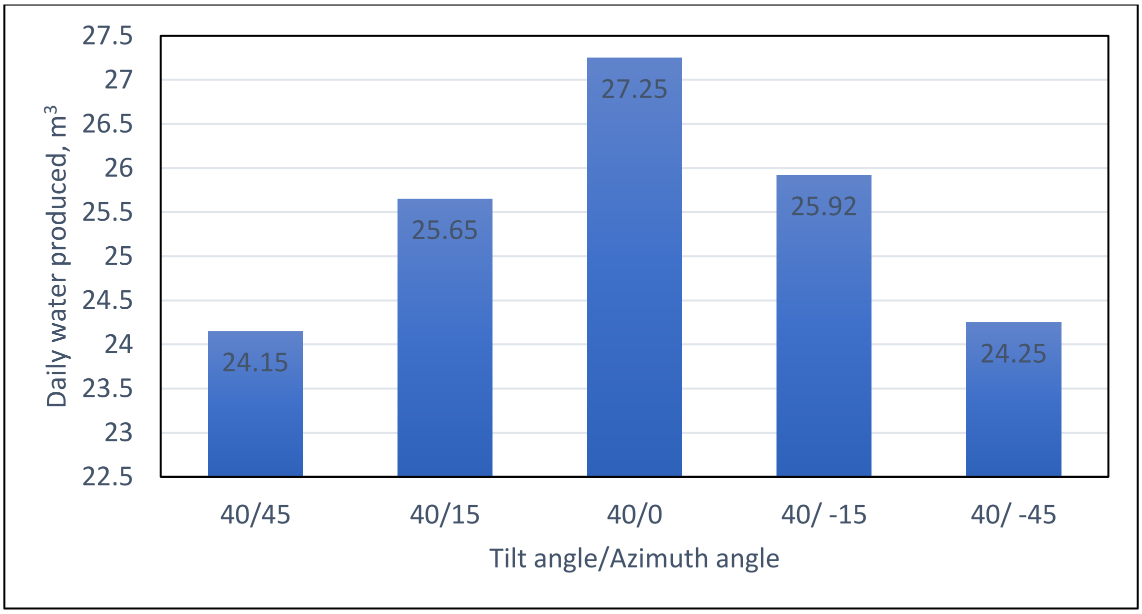

Fig. 16: Relation between the daily water produced, m3 with fixed tilt angle and different azimuth angles in Autumn Season

The relationship between electric power produced from the PV modules and time with various tilt angles and orientation is shown in Fig. 19 and Fig. 20. Figure 19 represents the relation between electric power produced from the PV modules (W) and time (hours) with fixed Azimuth angle and different tilt angles in Winter Season.

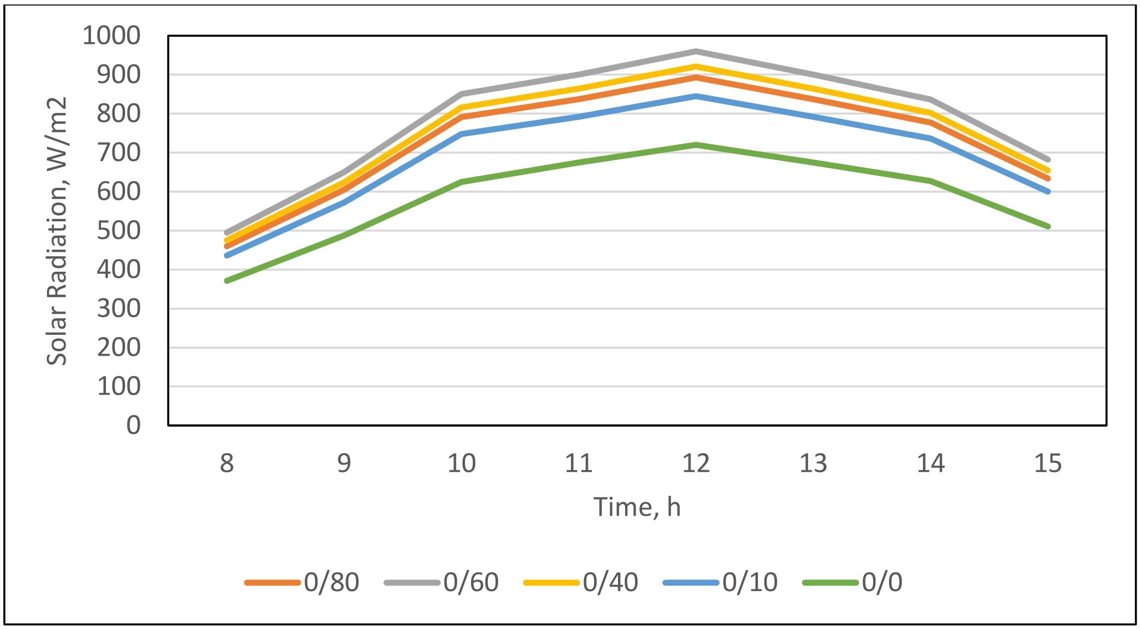

Fig. 17 Relation between solar radiation (W/m2) and time (hours) with fixed Azimuth angle and different tilt angles in Winter Season

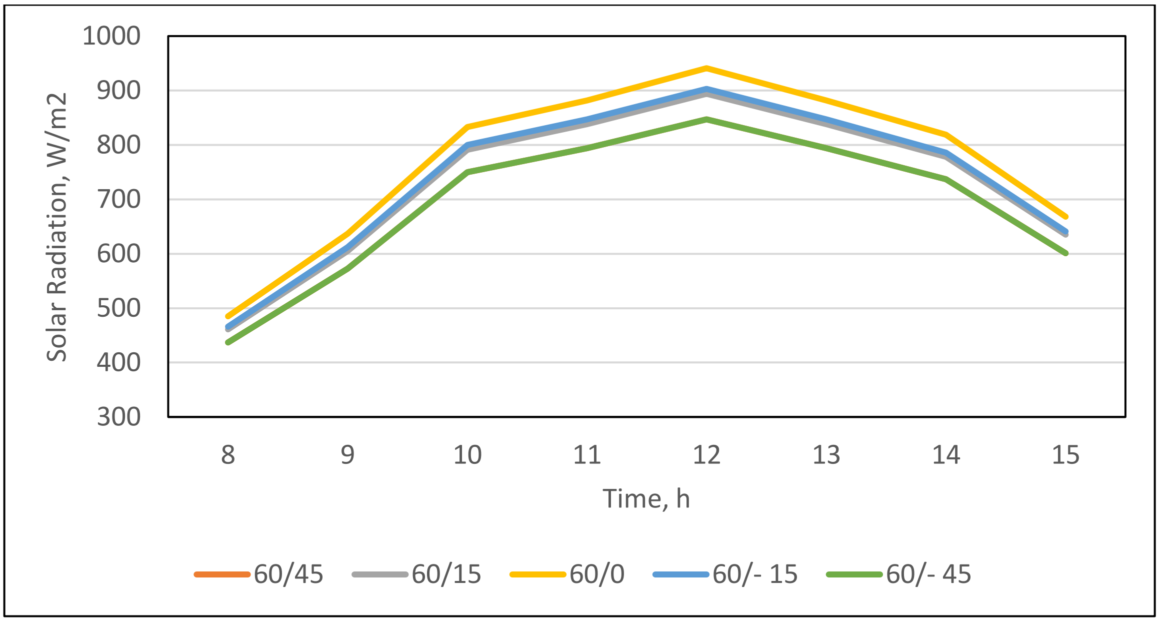

Fig. 18 Relation between solar radiation (W/m2) and time (hours) with fixed tilt angle and different Azimuth angles in Winter Season

It is found that for fixed azimuth angle (South facing), the higher values of electric power produced from the PV modules are for tilt angles equal 40, 60, 80, 10, and 0 respectively. Based on the results observed from Fig. 19, the maximum recorded electric power values are corresponding to tilt angle equal 40 and Azimuth angle equal 0. While Fig. 20 represents the values of electric power produced from the PV modules for a tilt angle equal 40 and different azimuth angles. It is found that the electric power values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

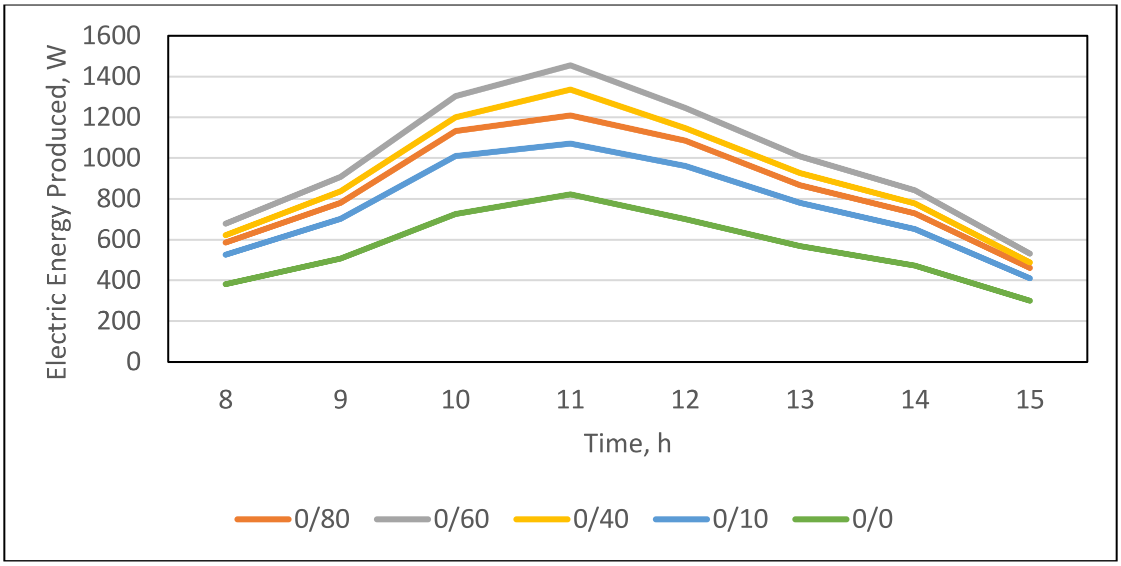

Fig. 19 Relation between electric power produced, W and time (hours) with fixed Azimuth angle and different tilt angles in Winter Season

Figure 21 describes the relation between daily water produced (m^3) with fixed azimuth angle (facing south) and different tilt angles. The results showed that the daily water produced are 21 m^3, 23.5 m^3, 26 m^3, 27.25 m^3, and 20.5 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 60 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80. While Fig. 22 represents the values of daily water produced based on its maximum value (azimuth angle equal 0 and tilt angle equal 60) and different orientations either towards east or west direction.

3.4. Effect of tilt angles and orientation in Spring Season

The relationship between solar radiation falling on the PV modules and time with various tilt angles and orientation is shown in Fig. 23 and Fig. 24. Figure 23 represents the relation between solar radiation (W/m^2) and time (hours) with fixed Azimuth angle and different tilt angles in Spring Season. It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules are for tilt angles equal 10, 40, 0, 60, and 80 respectively. Based on the results observed from Fig. 23, the maximum recorded solar radiation values corresponding to tilt angle are equal 40 and Azimuth angle equal 0. While Fig. 24 represents the values of solar radiation for a tilt angle equal 40 and different azimuth angles. It is found that the solar radiation values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0).

The relationship between electric power produced from the PV modules and time with various tilt angles and orientation is shown in Fig. 25 and Fig. 26.

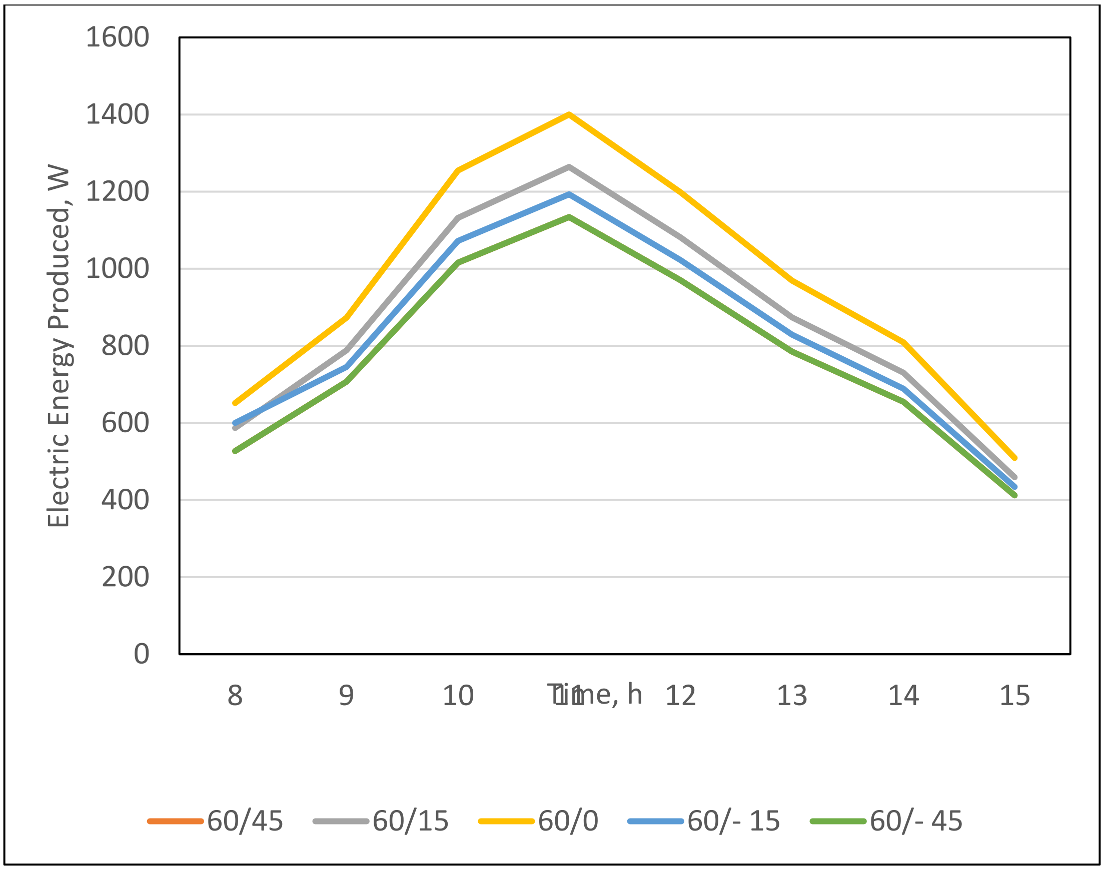

Fig. 20 Relation between electric power produced, W and time (hours) with fixed tilt angle and different Azimuth angles in Winter Season

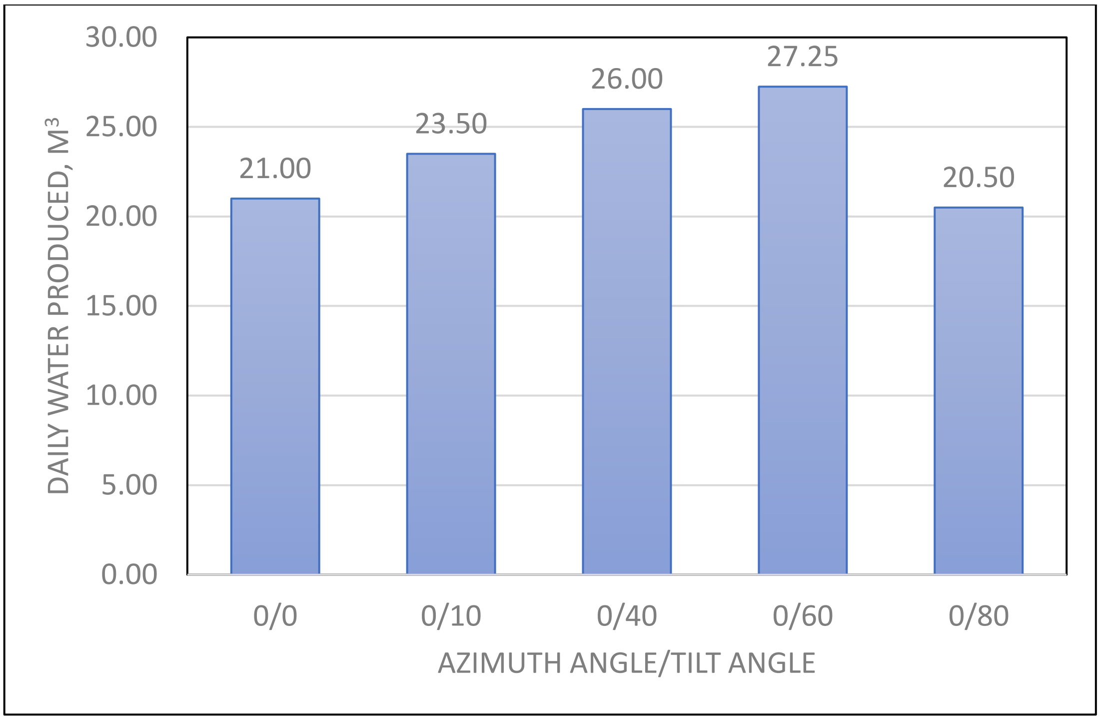

Fig. 21: Relation between the daily water produced, m3 with fixed azimuth angle and different tilt angles in Winter Season

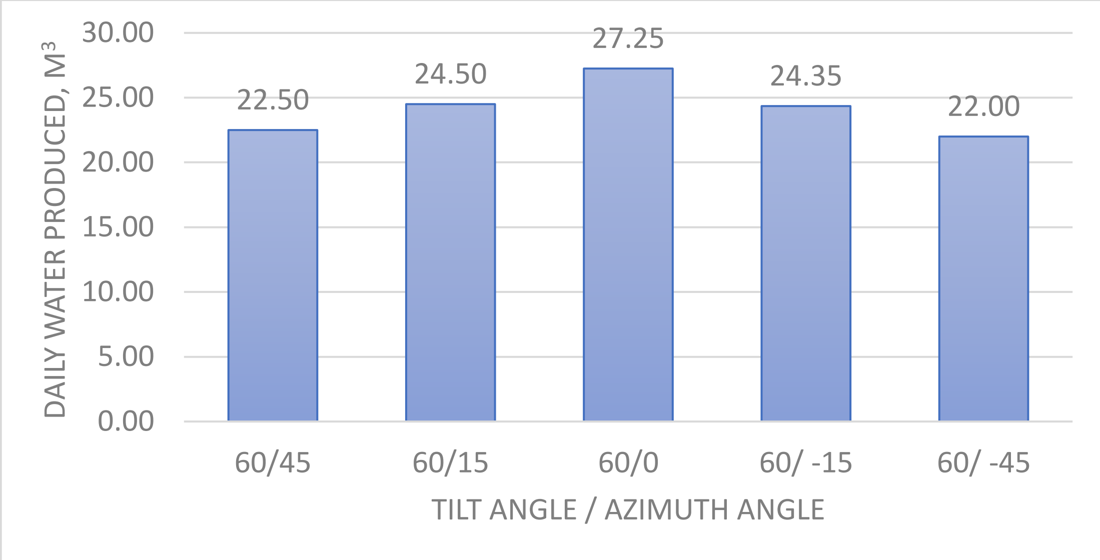

Fig. 22: Relation between the daily water produced, m3 with fixed tilt angle and different azimuth angles in Winter Season

Figure 25 represents the relation between electric power produced from the PV modules (W) and time (hours) with fixed Azimuth angle and different tilt angles in spring Season. It is found that for fixed azimuth angle (South facing), the higher values of electric power produced from the PV modules are for tilt angles equal 10, 40, 0, 60, and 80 respectively.

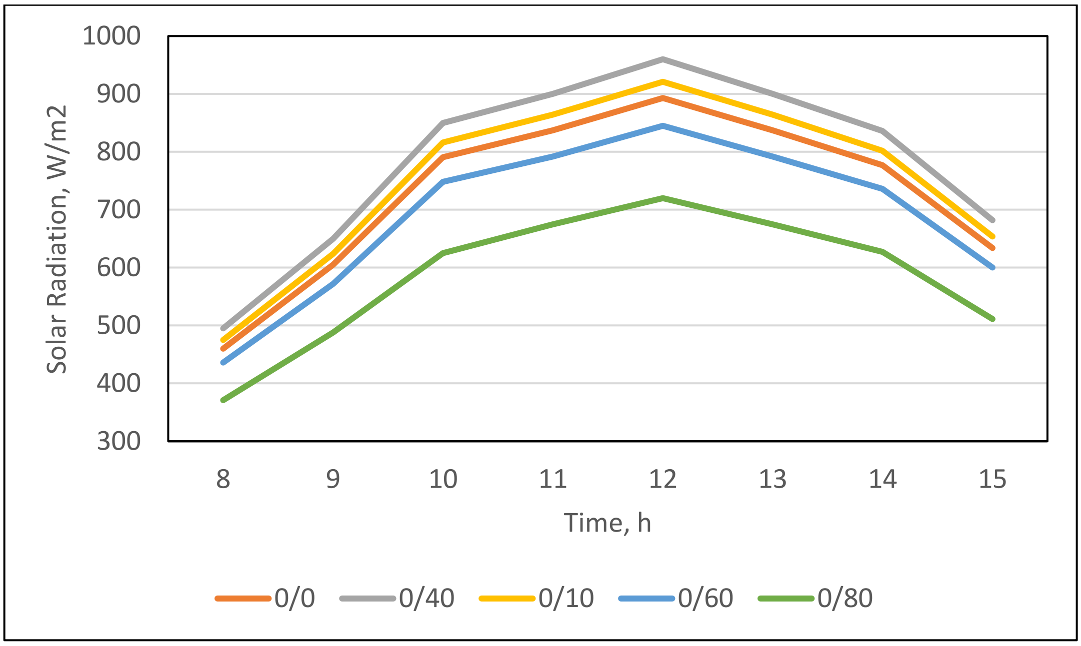

Fig. 23 Relation between solar radiation (W/m2) and time (hours) with fixed Azimuth angle and different tilt angles in Spring Season

Based on the results observed from Fig. 25, the maximum recorded electric power values are corresponding to tilt angle equal 40 and Azimuth angle equal 0. While Fig. 26 represents the values of electric power produced from the PV modules for a tilt angle equal 40 and different azimuth angles. It is found that the electric power values recorded lower values if the solar PV module is oriented towards the east and west and the higher values obtained when the PV modules is facing south (azimuth angle =0). Figure 27 describes the relation between daily water produced (m^3) with fixed azimuth angle (facing south) and different tilt angles. The results showed that the daily water produced are 23.5 m^3, 26 m^3, 27.5 m^3, 25.5 m^3, and 22.5 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 40 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80. While Fig. 28 represents the values of daily water produced based on its maximum value (azimuth angle equal 0 and tilt angle equal 40) and different orientations either towards east or west direction.

3.5. Daily water produced with different orientations of the four seasons

The daily water produced, m^3 with fixed azimuth angle and different tilt angles for four Seasons is presented in Fig. 29. it is found that for south facing and tilt angles 0, 10, 40, and 80, the maximum value of daily water produced is occured in Summer while the minimum value is occoured in winter. While the maximum value of daily water produced is occured in winter and the minimum value is occoured in autumn for south facing and tilt angle equal 60. Figure 30 presents the relation between the daily water produced, m^3 with different tilt angle and orientations in four Seasons. It is found that the daily water produced, m^3 is affected by both tilt angles and azimuth angles in each season. As an example there is a maximum value of the daily water produced, m^3 in summer with tilt angle equal 10 and azimuth angle equal 0 while the maximum value attained in winter with tilt angle equal 60 and azimuth angle equal 0. The maximum value of summer, autumn, winter, and spring were 32 m^3, 27.25 m^3, 27.25 m^3, 27.50 m^3 for south facing and tilt angles 10, 40, 60, 40 respectively.

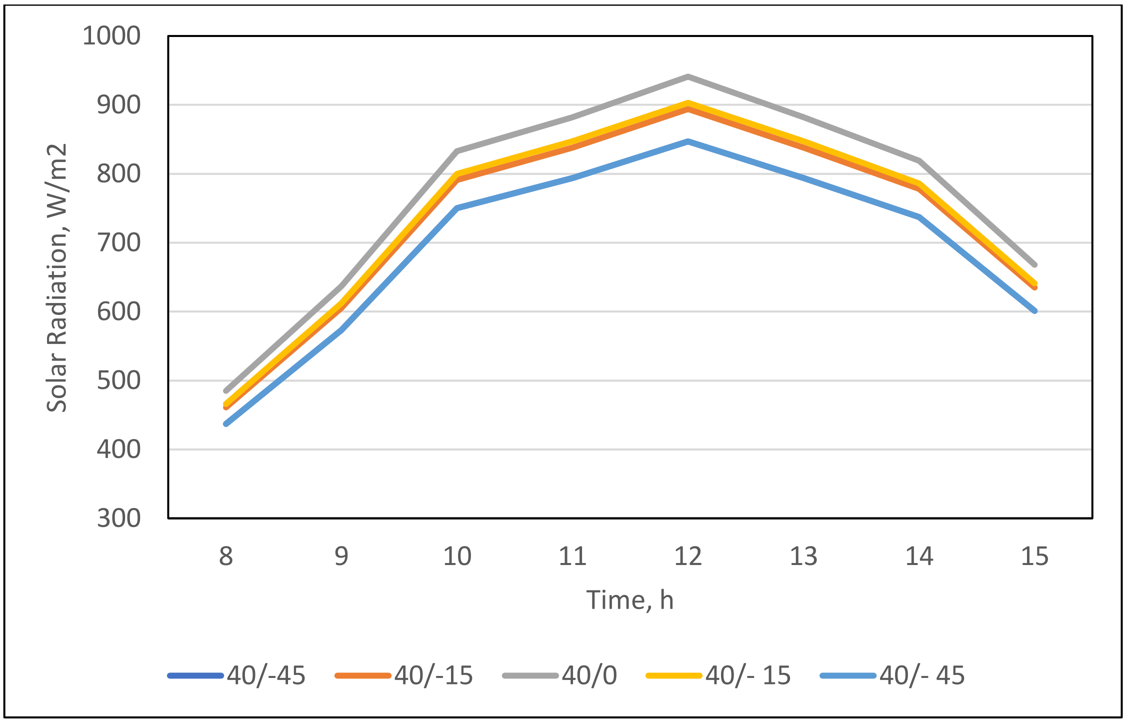

Fig. 24 Relation between solar radiation (W/m2) and time (hours) with fixed tilt angle and different Azimuth angles in Spring Season

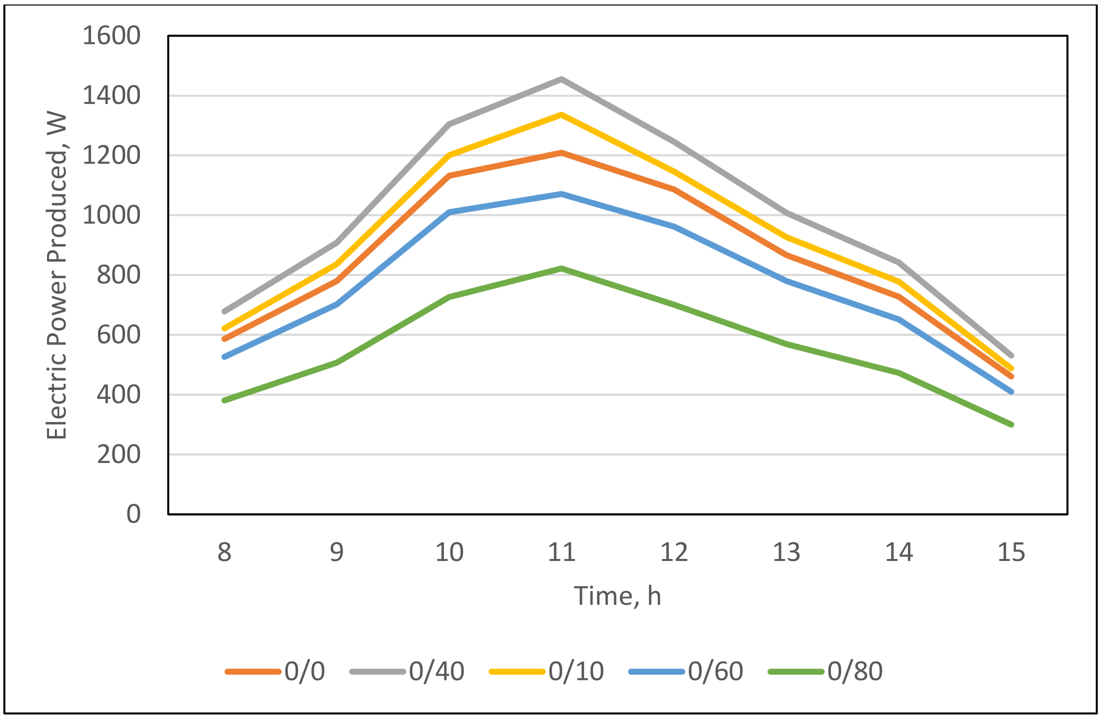

Fig. 25 Relation between electric power produced, W and time (hours) with fixed Azimuth angle and different tilt angles in Spring Season

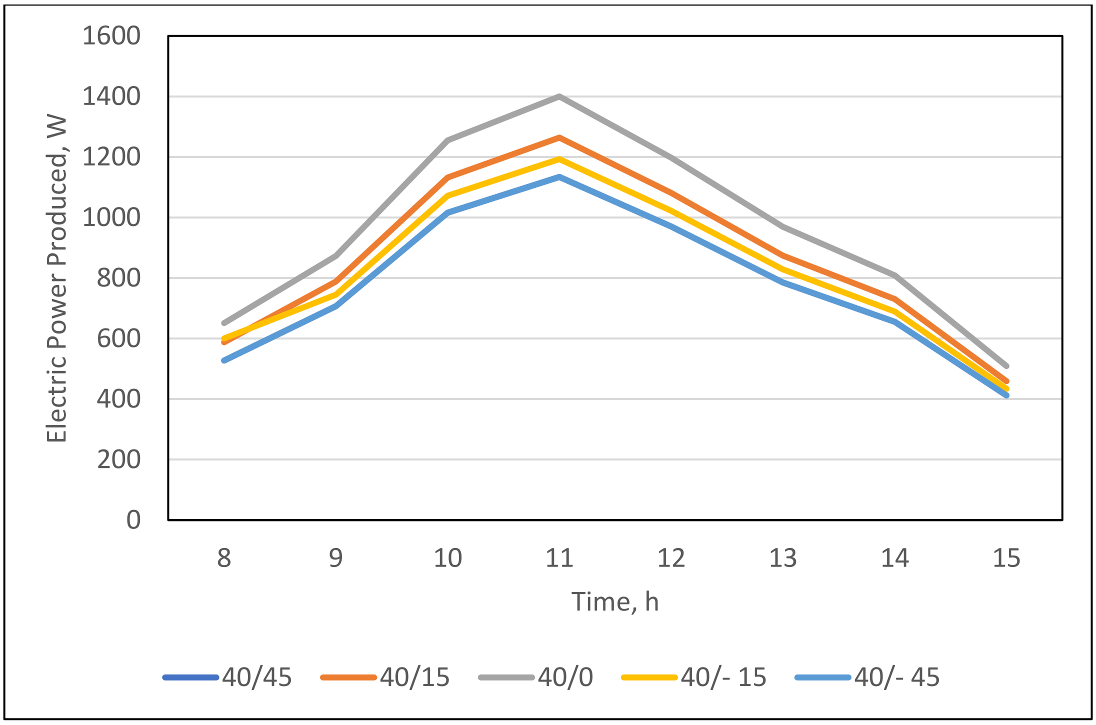

Fig. 26 Relation between electric power produced, W and time (hours) with fixed tilt angle and different Azimuth angles in Spring Season

The percentage of the daily water produced, m^3 based on the maximum value in the year is presented in Fig. 31. It is cleared that the tilt angle and orientations are very important factors that affect the performance of the PVwater pumping system. While Fig. 32 presents the percentage of the daily water produced, m^3 based on the maximum value in the year with different tilt angles and orientations.

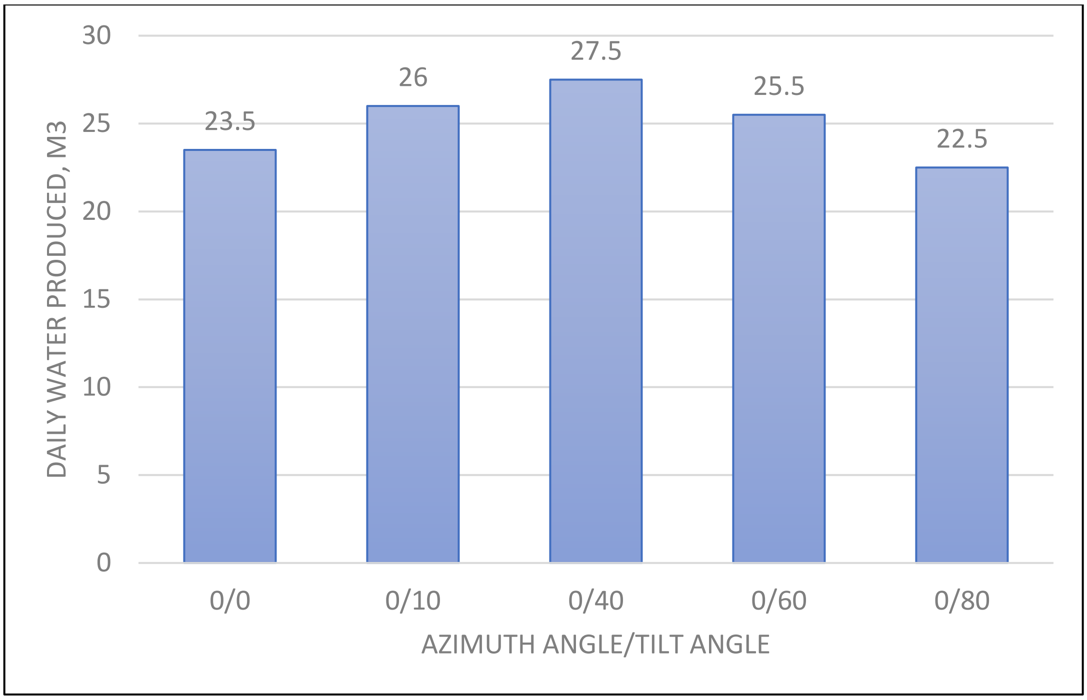

Fig. 27: Relation between the daily water produced, m3 with fixed azimuth angle and different tilt angles in Spring Season

The percentage of the daily water produced, m^3 based on the maximum value in each season is presented in Fig. 33. It can be seen that each tilt angle and azimuth angle has a corresponding value of daily water produced in each season. Figure. 34 presents the percentage of the daily water produced, m^3 based on the maximum value in each season with different tilt angles and orientations.

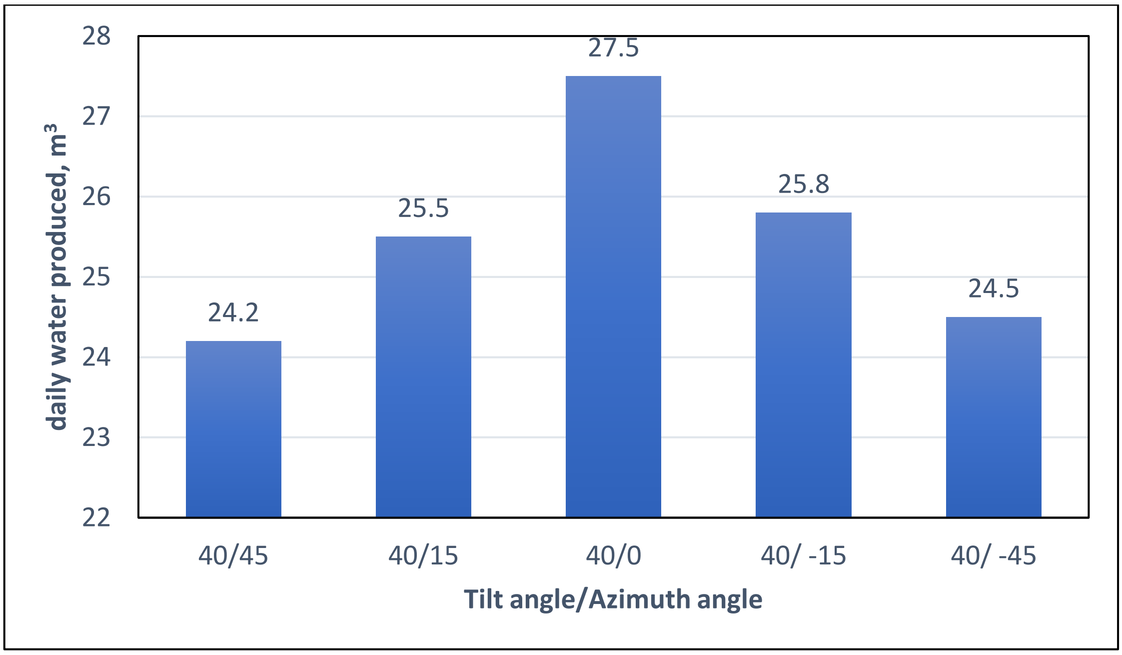

Fig. 28: Relation between the daily water produced, m3 with fixed tilt angle and different azimuth angles in Spring Season

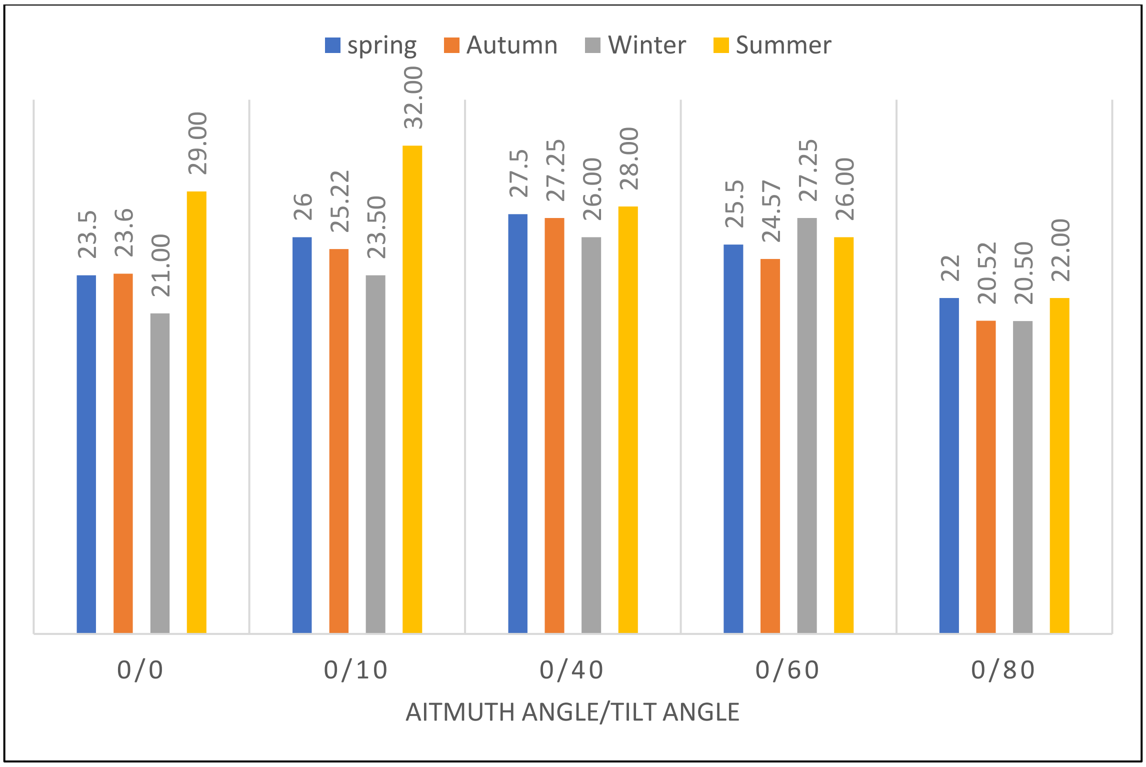

Fig. 29: Relation between the daily water produced, m3 with fixed azimuth angle and different tilt angles for four Seasons

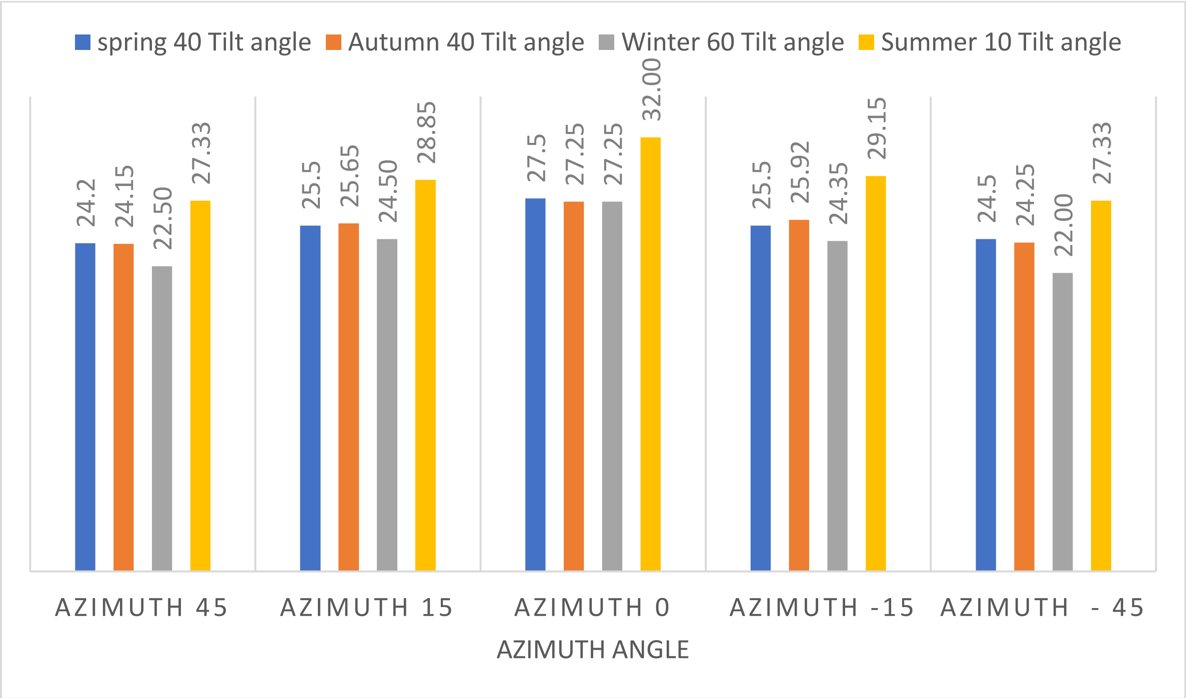

Fig. 30: Relation between the daily water produced, m3 with different tilt angle and orientations in four Seasons

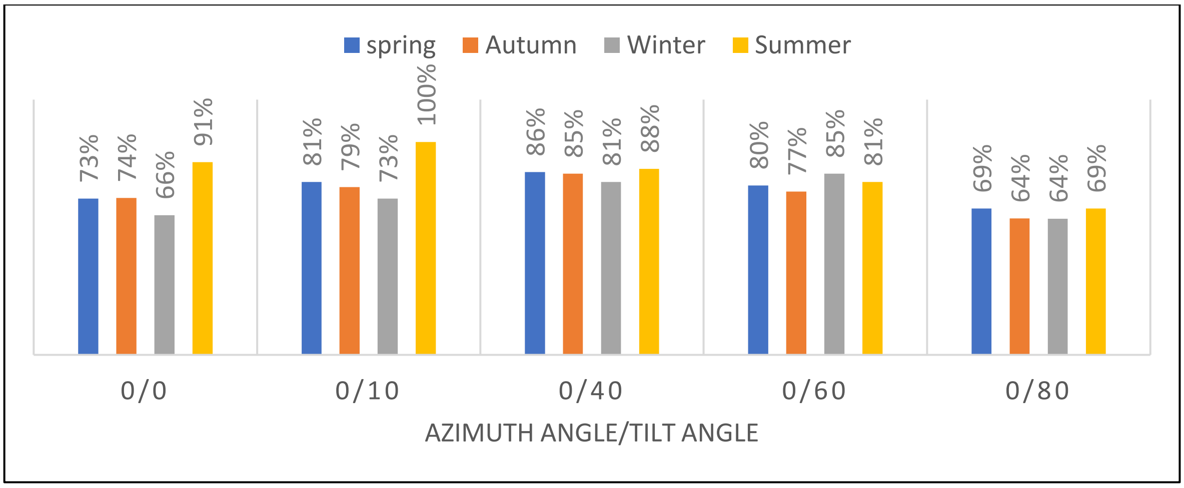

Fig. 31 The percentage of the daily water produced, m3 based on the maximum value in the year with fixed azimuth angle and different tilt angles

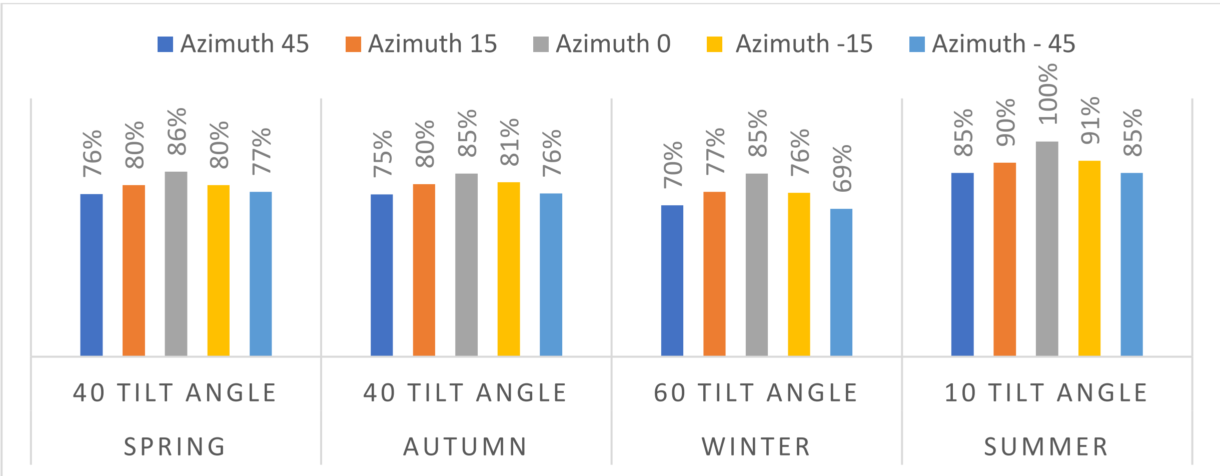

Fig. 32 The percentage of the daily water produced, m3 based on the maximum value in the year with different tilt angles and orientation

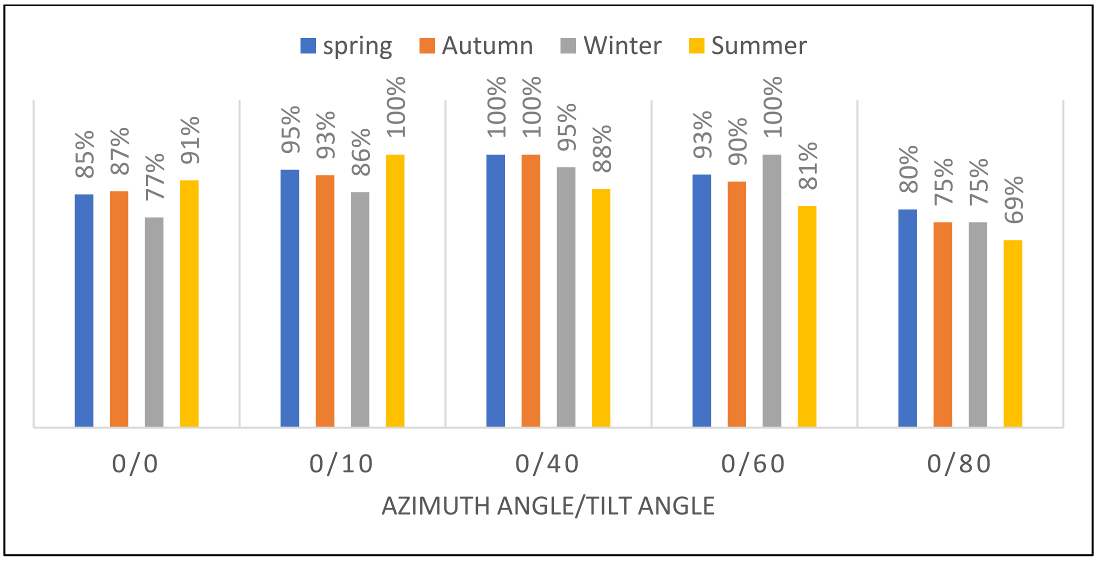

Fig. 33 The percentage of the daily water produced, m3 based on the maximum value in each season with fixed azimuth angle and different tilt angles

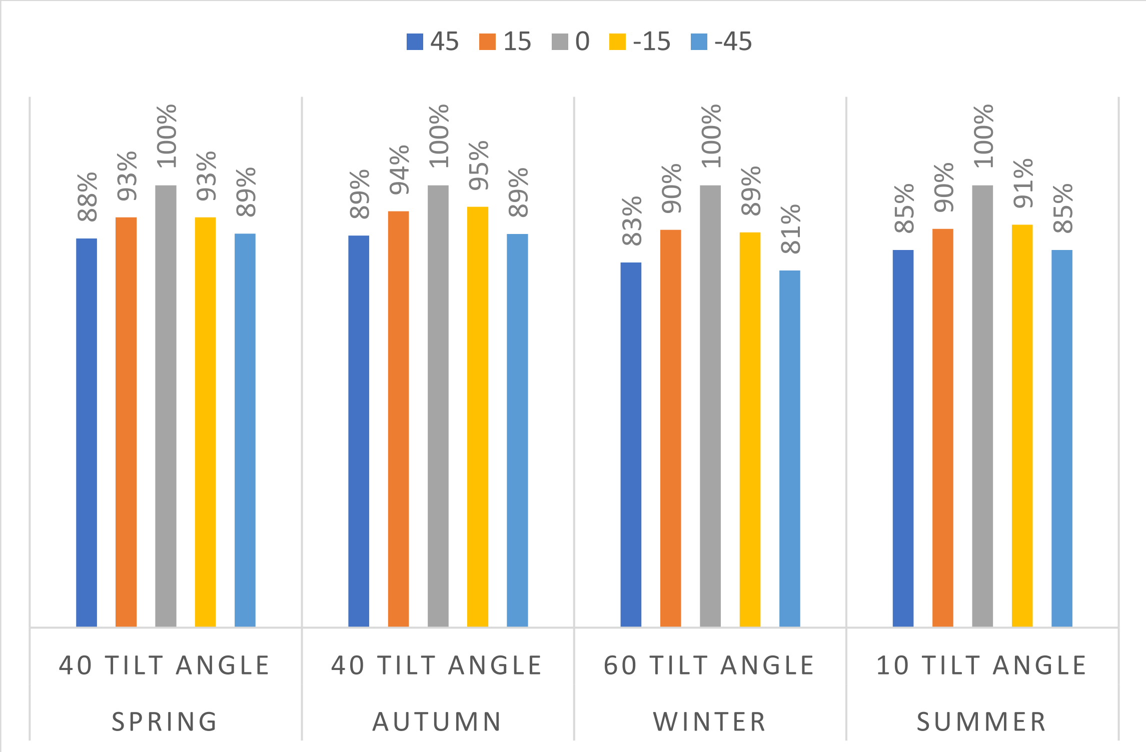

Fig. 34 The percentage of the daily water produced, m3 based on the maximum value in each season with different tilt angles and orientation

4. Conclusions and Recommendations

Solar water pumping system has several advantages as alternative energy source instead of diesel and electric generators. It is Eco-friendly, simple, easy to install, and available in each site location. The main components of the PV water pumping system are PV modules, inverter, control, metallic structure, and submersible or surface water pump. The main parameters affecting the performance of the solar water pumping system are the PV module tilt angle and orientation as they affect the solar radiation falling, electric power output and amount of daily water produced. The current study evaluated the system performance in the four seasons at different tilt angle and orientations. Some concluded remarks can be listed as below:

1- In Summer Season It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules and consequently the electric power output are for tilt angles equal 10, 0, 40, 60, and 80 respectively. It is concluded that the maximum recorded solar radiation values and the electric power output are corresponding to tilt angle equal 10 and Azimuth angle equal 0. It is found that the daily water produced are 29 m^3, 32 m^3, 28 m^3, 26 m^3, and 22 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 10 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80.

2- In Autumn Season It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules and consequently the electric power output are for tilt angles equal 40, 10, 0, 60, and 80 respectively. It is concluded that the maximum recorded solar radiation values and the electric power output are corresponding to tilt angle equal 40 and Azimuth angle equal 0. It is found that the daily water produced are 23.6 m^3, 25.22 m^3, 27.25 m^3, 24.57 m^3, and 20.52 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 40 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80.

3- In Winter Season It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules and consequently the electric power output are for tilt angles equal 60, 40, 80, 10, and 0 respectively. It is concluded that the maximum recorded solar radiation values and the electric power output are corresponding to tilt angle equal 60 and Azimuth angle equal 0. It is found that the daily water produced are 21 m3, 23.5 m3, 26 m3, 27.25 m3, and 20.5 m3for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 60 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80.

4- In Spring Season It is found that for fixed azimuth angle (South facing), the higher values of the falling solar radiation on the PV modules and consequently the electric power output are for tilt angles equal 10, 40, 0, 60, and 80 respectively. It is concluded that the maximum recorded solar radiation values and the electric power output are corresponding to tilt angle equal 40 and Azimuth angle equal 0. It is found that the daily water produced are 23.5 m^3, 26 m^3, 27.5 m^3, 25.5 m^3, and 22.5 m^3 for tilt angle 0,10,40,60, and 80 respectively. The maximum daily water produced obtained at azimuth angle equal 0 and tilt angle equal 40 while the lowest value of daily water produced is obtained at azimuth angle equal 0 and tilt angle equal 80.

1- It is found that for south facing and tilt angles 0, 10, 40, and 80, the maximum value of daily water produced is occured in Summer while the minimum value is occoured in winter. It is found that the daily water produced, m^3 is affected by both tilt angles and azimuth angles in each seasons, the maximum value of the daily water produced, m^3 in summer with tilt angle equal 10 and azimuth angle equal 0 while the maximum value attained in winter with tilt angle equal 60 and azimuth angle equal 0. The maximum value of summer, autumn, winter, and spring were 32 m^3, 27.25 m^3, 27.25 m^3, 27.50 m^3 for south facing and tilt angles 10, 40, 60, 40 respectively.

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