INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
A. Alsakarneh et al., Vol.13, No.3, September, 2023

Design, Development and Control of Dual-Axis Solar Tracking System

Amjad Alsakarneh*‡, Taha Tabaza**, Tom sunny***, Deviprakash Jyothishmathi***, Nezar Qudah****, Ahmad Afghani**

*Department of Mechanical Engineering, Hijjawi Faculty for Engineering Technology, Yarmouk University, Irbid, Jordan

**Department of Mechanical Engineering, Faculty of Engineering and Technology, Al-Zaytoonah University, Amman, Jordan.

***Department of Mechanical Engineering, Fujairah Men College, HCT, Fujairah, UAE

****Department of Mechanical Engineering, School of Engineering Technology, Al-Hussein Technical University, KHBP, Amman, Jordan

‡ Corresponding Author; Yarmouk University, Irbid, Jordan, Tel: +962 272 11111, Amjad.Alsakarneh@yu.edu.jo, Amjad_Sakarneh@yahoo.com

Received: 10.11.2022 Accepted:26.01.2023

Abstract- A tremendous number of solar tracking systems are available in the market, no design however offers a fully autonomous operation that could track the sun with no prior information about the location, or the season. The proposed paper presents a design, development and control of dual-axes solar tracking systems. The tracking system consists of two DC-motor for two different axes, the incidence and declination angles, and a set of solar sensors. A set of sensors is employed to acquire the required data to compute the optimum zenith and azimuth angles. The advantage of the proposed that it can be used anywhere with no information needed regarding latitude nor longitude coordinates. The experimental results show a significant improving, like 76%, of performance obtained using dual axes tracking system compared with the fixed horizontal surfaces in the summer in Jordan, and 41% in winter.

Keywords Dual Axes, Sun Tracking systems, Solar Energy, Solar Sensors, Zenith Angle, and Azimuth Angles.

1. Introduction

Solar energy is one of the most promising renewable energy resources that has a huge number of applications over the vast world. The project proposes designing a dual axes solar tracking system, this includes designing supporting frame of the system. As a matter of fact, solar tracking system have been employed widely in the last two decades for many various things such as steam generation, and water heating [1]. The principle of tracking system lies in utilizing a device that is able to orient a solar panel towards the sun to get the maximum amount of sunlight. “The systems are oriented with optimal tilt angles towards the equator from the horizon to maximize the solar radiation affects on the solar collectors and panels” [2]. Compared to the fixed systems, the tracking ones are more important and beneficial due to the big amount of power they gain and the economic value they lend to the solar energy applications. In general, there are two types of solar tracking systems, single and dual axes tracking systems. More details about types and tracker categories will be presented in the following sections.

2. Literature Review

The idea of active tracking systems dated back to 1975 when an algorithm used by McFee to measure the power gained by receivers in solar power systems and decided on its density. Different control types were used to fix and organize the active tracking systems such as electric optical sensor, microprocessors and auxiliary PV cells [3-4]. After that, in 1984 dual axis tracking systems with azimuth and elevation were made by Zogbi and Laplaze, they used electric optical sensors and an amplifier to compare the received signals from the sensors [5]. In 1986, depending on the shadow method, Rumala created a loop control tracking system with four photo-resistors [6]. “The photo-resistors are under a pair of cylinders mounted back-to-back East-West (E-W) and North-South (N-S). The control circuit is a signal conditioning circuit using a low pass filter, which feed an amplifier” [1]. In 1996, a single axis tracking system was used for the first time by Kalgirou, the design included three light dependent resistors (LDR) to identify the concentration state of the collector and detects the presence of shadowing. Then, a new design of dual axis solar tracking system was presented by Khalifa and Almutawalli to track the sun horizontally and vertically every 3 minutes and 4 minutes respectively [7].

In terms of passive tracking systems, Zomewords -an American company- developed the first system in 1969. Another passive tracking system with the use of shape memory alloy was developed in 1994 by Poulek book by Zomeworks [8]. The alloy is changed and deformed at a temperature below 70°C, it returns to the original form when it is heated at a higher temperature and acts as a heat engine during the warming cycles. The best place for using the passive tracking systems is near the equator because of abundant sun irradiance and the low difference between azimuth and elevation angles and its wide use in isolated applications. On the other hand, this system drawback lies in its inaccuracy, low efficiency and lack of sustainability in bad weather.

Tremendous studies and researches have been conducted around the world about solar tracking systems and their applications in certain areas such as Australia, Canada, China, Germany, India, and Middle East countries [9-11]. Depending on the movement degree of freedom, the solar tracking systems are classified into two major types that are single axis and dual axis tracking systems. In addition, the solar tracker drives are also divided into five categories based on their tracking technology: active, passive, chronological, semi passive and manual tracking [12-15]. Studies show that active tracker is the most common type used and the chronological type is in the second place. Under the umbrella of the two main types, subtypes can be easily noticed in other studies and applications like vertical tracking, polar tracking, azimuth tilt tracking and so on.

Recent studies about single axis [3, 12] and dual axis [16-17] or both [18-19] are discussed in this study. In these studies, special types of tracking systems are also discussed. These special types include a north-south axis, azimuth tracking, horizontal tracking, polar tracking, vertical tracking, azimuth and altitude tracking, azimuth and elevation tracking and so on. The statistics investigated in this study shows that 42.57% of studies focus on the single axis while 41.58% focus on dual axis. About 16% of studies investigate both [18-19].

Comparison between the two main types indicates that dual axis is more expensive, more complicated and needs more instruments than a single axis. However, the dual tracking axis gains more solar energy because it tracks the sun. In terms of applications, single axis trackers are favorably used in linear Fresnel solar systems and parabolic collectors whereas solar tower systems and dish use dual axis trackers [1].

Later, Zhong et al investigated sun-tracking technique called inclined south north axis (ISNA-3P) [20]. The solar panel is daily adjusted at these directions sun: eastward, southward, and westward in the morning, noon, and afternoon where solar panels rotate about the inclined south north axis. Hong et al tried to increase the electricity generated by a smart photovoltaic blind by using direct and indirect tracking methods [21]. In this regard, the single axis trackers track the sun from east to west while the dual axis one tracks it in east west motion and north south motion.

Compared to the dual axis tracking systems, it can be noticed that single axis ones are simpler and cheaper, and it consumes less energy. However, the single axis trackers are still less efficient than the dual ones in terms of energy gained. As a result, researchers keep trying to improve its efficiency by comparing the output of fixed and single axis tracking systems. Others presented different ways and ideas to enhance the performance of this tracking systems by using PLC, hydraulic drives, solar desalination, thermos-syphon heater, solar concentrators, and other mathematical methods. As indicated from the above studies, a lot of studies and researchers have been attempting to vitalize the use of dual axis tracking systems by overcoming their high cost and complexity. Full details about all solar tracking system are discussed by a review article published recently by Hafez et al [1].

In recent literature, several studies have been conducted to enhance the efficiency of photovoltaic solar panels and optimize their performance. In one study [22], researchers implemented an adaptive neuro fuzzy inference system (ANFIS) based maximum power point tracking (MPPT) technique to improve the efficiency of the panels. Another investigation [23] compared and evaluated the performance of an automatic Smart Sun tracking system with a manual Sun tracking system, with the goal of optimizing solar panel efficiency. Furthermore, researchers in [24] focused on energy-economic optimization of thin-layer photovoltaic systems installed on domes and cylindrical towers, aiming to identify the most efficient and cost-effective configurations for generating solar energy.

Temperature and illumination were explored in [25] to understand their impact on the efficiency of photovoltaic systems. Additionally, the evaluation of wind energy conversion systems using a newly developed wind turbine emulator was the focus of another article [26]. The study aimed to assess the performance and effectiveness of these systems, potentially contributing to the advancement of smart grid technologies. Moreover, the effects of faults in solar panels on the production rate and efficiency of solar energy systems were investigated in [27]. By analyzing various faults, the study aimed to provide insights into performance degradation and efficiency reduction caused by these faults, thus facilitating effective fault detection and maintenance strategies.

3. Theory, Design and Control of Tracking System

3.1 Theoretical background of mechanism adopted for the tracking system

The below section explains how the proposed solar tracking system works effectively. It starts with the brief explanation of the coordinate system using the method of pseudo azimuthal system to show the sun trajectory and orientation of tracking system.

A horizontal coordinate system helps to determine the three-dimensional spherical surface to determine the exact position on sun which includes altitude and azimuth angle. The location straight above the tracking system is called the zenith. The azimuth angle is the horizontal angle which the sun makes with the reference north direction. The path of sun is shown by the horizontal coordinate system shown in Fig. 1.

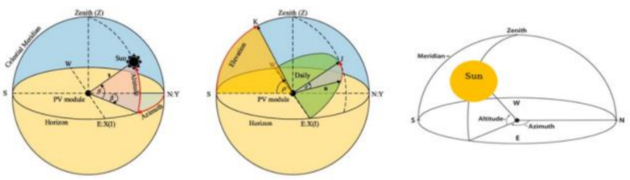

Fig. 1. The horizontal coordinate system adopted for tracking system [28].

By applying the projection method with respect to the horizon plane from above fig helps to find the coordinates. The azimuth angle (β) refers to the difference angle of north-south (N-S) axis to the vector projection on the horizontal plane. The sun will follow certain elevation level with respect to horizontal plane, hence considered the three-dimensional unit vector represented the sunlight incident to observer. The altitude angle (α) represents the angle of sunlight measured from horizontal plane to zenith which can be 0° to 90° as it's measured by height of sun and sun follows daily travel path from east to west. Accordingly, the daily angle (ε) and elevation angle (ρ) are obtained in terms of altitude angle (α) and the azimuth angle (β). The tracking of the sun needs to be accomplished by following the movement of sun by two axes, one of which is daily axis and other is based on summer/ winter axis. Hence the dual axis solar tracking system finds its importance which is used in design and calculations [28].

3.2 Photovoltaic solar Panel

Solar panels entrap the suns energy and converts it to electricity actively. Photovoltaic cells are arranged in a grid-like pattern on the surface of the solar panel. Mainly these PV cells are made with crystalline silicon. Solar cells work similar to large semiconductors. When sun rays interact with the PV cells, the silicon cell absorbs the energy from the sun and the electrons begin to move creating a flow of electric current. The photons striking on the surface of PV panel allows electrons to be knocked out of their orbits and released and forms energy. The electric fields in the PV cells pull these free electrons in a directional current, from which the PV cell can generate electricity [29].

The photovoltaic panel module generates DC power depends upon the solar irradiation incidents on module. To obtain the maximum possible power, the current and voltage characteristics needs to be taken care which depends on irradiation incident on module. The sun light incidents on the module changes from time to time causes variation in irradiation on surface of PV panel. The sun light incident to the PV panel module surface should be perpendicular to the surface to improve the irradiation. This can be achieved by the dual axes solar tracking system to follow the sun trajectory by using altitude-azimuth angle system, Fig. 2 shows the axes of rotation of dual axes system [29] [30].

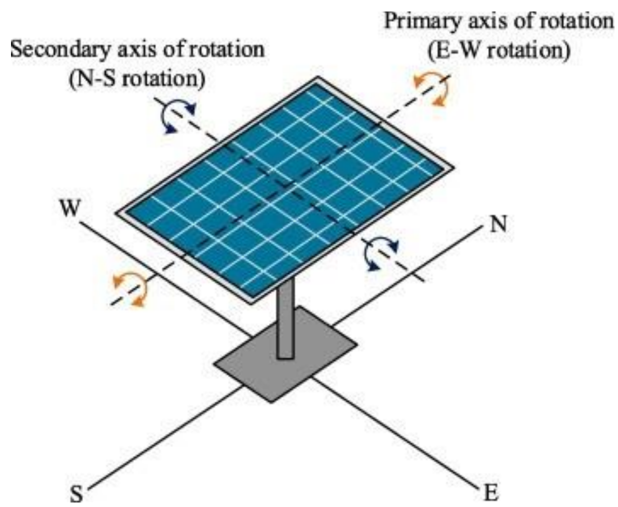

Fig. 2. The axes of rotation of the solar tracking system [29].

3.3 Mechanical Structure

This section explains the mechanical structure followed in the designed solar tracking system. The solar panel of polycrystalline silicon type PV cell, of dimensions 116.6 cm X 65.5 cm, is used for the designed tracking system as it is shown in Fig. 3. Based upon the dimensions and weight of the panel need to be used, the base frames for the tracking system is designed and fabricated.

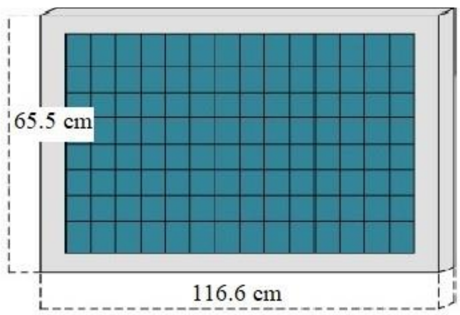

Fig. 3. PV panel module dimensions.

The tracking system base frame consists of the following parts as shown in Fig. 4. Aluminum is the material used for frame. Base support which comprises of four rectangular rods of L50xW10xH10 cm which is placed in cross shape to each other to the main support rod, the required provision of screws is made on the on rectangular and main support rods to assemble in the shape as shown in the Fig. 3. Main support pillar of dimension L125XW10XH10 cm perpendicular to the center of the base, the base support rectangular rods are joined with this center pillar.

Axis number 1, components which includes frame with rectangular shape of length 106.6 cm and space between rectangular frames of width 10 cm as shown in Fig. 4. This part is joined with the main support pillar with the screw provisions made. Axis number 2, components which includes with rectangular shape Length 116.6 cm and space between rectangular frame of width 56 cm are fixed outside the inside rectangle of axis 1 and joined with axis 1 frame using screw provisions made.

In order to control the movement of two axes on tracking system, screw motor type actuator is used for both axes. The base of first actuator is fixed on the main support pillar at 20 cm from the top, and tip is fixed at 32 cm from axis1 rectangular frame. The base of second actuator is fixed on additional steel terminal fixed at corner of axis number 1 frame at 30 cm, and the tip of actuator is fixed at the corner of the axis number 2 rectangular frame. The Axis number 1 helps to get the primary axis of EW rotation in NS axis, similarly, axis number 2 helps to maintain the secondary axis of NS rotation on EW axis. Limit switches are employed at the actuators in order to avoid the damage which may be caused by limit in reach of both axes.

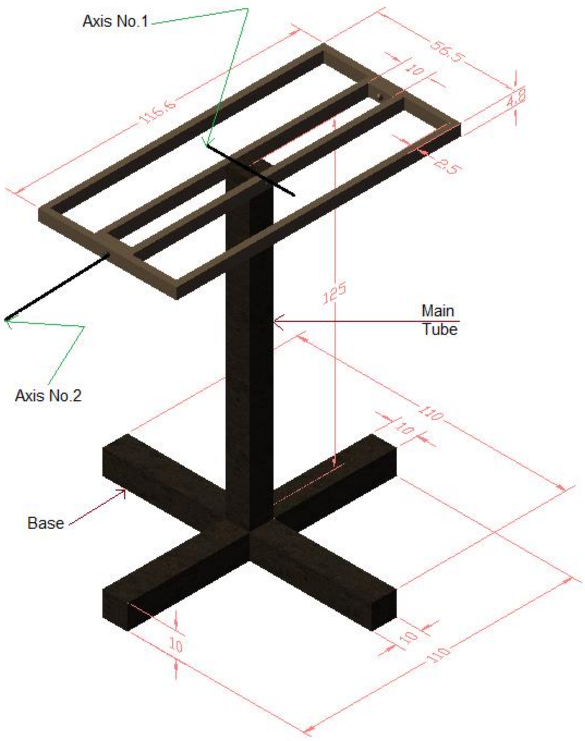

Fig. 4. The base frame of the proposed tracking system.

3.4 Tracking Mechanism and Control

Screw type motor actuators is used for the control of both axes. To track the sun, a Resistance Temperature Detector (RTD) is utilized, it is a sensor whose resistance changes with change in temperature. The RTD type sensors were used as a feedback to the controller, sensors give the control unit a signal in order to command the actuator to move up/down and/or right/left. The four RTD sensors were fixed on a horizontal wood base with a 4x4 cm rectangular shape, each sensor in a corner as shown in Fig. 5. The sensors were separated using two cross wood plates with 12 cm height. The PV panel then were fixed to the wood base that hade the sensors at its edge to be horizontal with it.

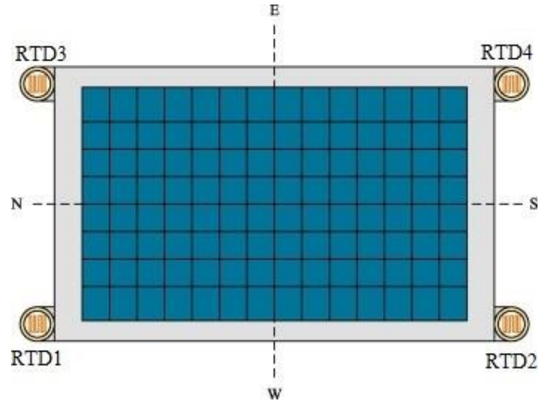

Fig. 5. The RTD sensors on the PV panel.

Arduino Uno is a microcontroller board based on the ATmega328P with 14 digital I/O pins and 6 analog inputs. The control unit Arduino Uno receives the analog signal from RTD sensors, based on the collected signals, the Arduino Uno commands actuators to rotate the panel to the optimum direction. The RTD sensors were connected to the H-Bridge and regulates the convertor supply to the control unit with suitable voltage of 5 Volt. Fig. 6, 7, and 8 show the electronic circuit, the block diagram of the tracking system, and the Arduino unit used in the proposed system, respectively.

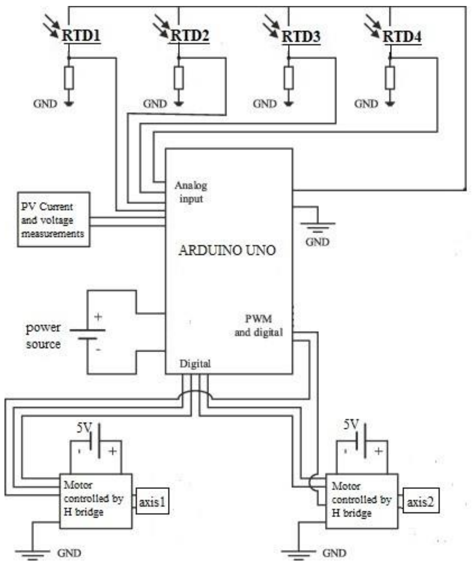

Fig. 6. Overview of electronic circuit used for solar tracking system.

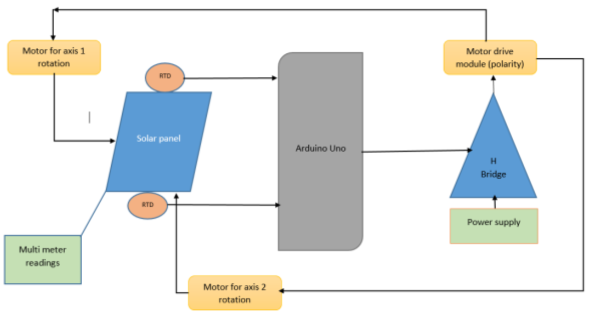

Fig. 7. The block diagram of tracking system control.

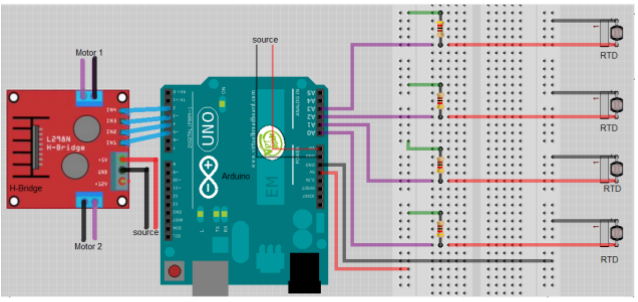

Fig. 8. The control unit of Arduino.

4. Results and Discussion

By using the voltage and current recorded by the data logger, the power was calculated on excel sheet, a total number of 82 and 60 measured values were taken daily, and for two months, in summer and winter seasons, respectively. In Summer Season, Fig. 9 shows the power-time relation of dual axis solar tracker and fixed axis solar panel. The power in fixed axis is 1178 Whr every day for 100 Wp, whereas, the power of the dual-axes solar tracking system is 2082 Whr, also for 100 Wp solar, which means the increasing in power about 76%; i.e. 903 Whr per day in summer season.

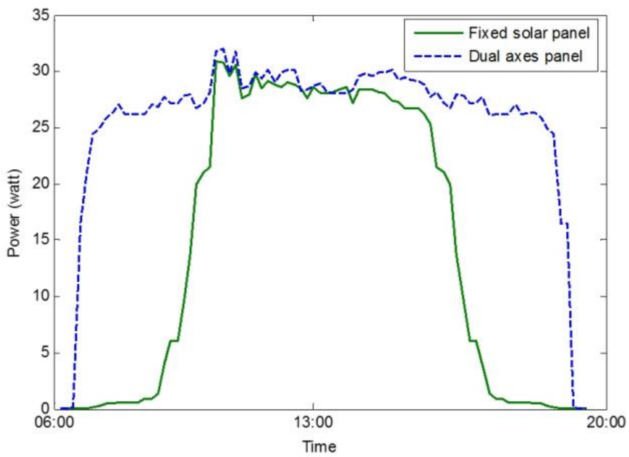

Fig. 9. The measured power from sunrise to sunset during the summer solstice for fixed solar panel and dual axes panel.

It is known that the solar radiation in winter is less than summer as a result the power generated by the PV panel will be decreased. For that reason, the proposed investigated the effectiveness of tracking system during winter time, Fig. 10. For the fixed axis, the total energy collected is 633 Whr per day for 100 Wp solar, while the dual axis solar tracker collected 1532 Whr per day, which means the power increased about 41%.

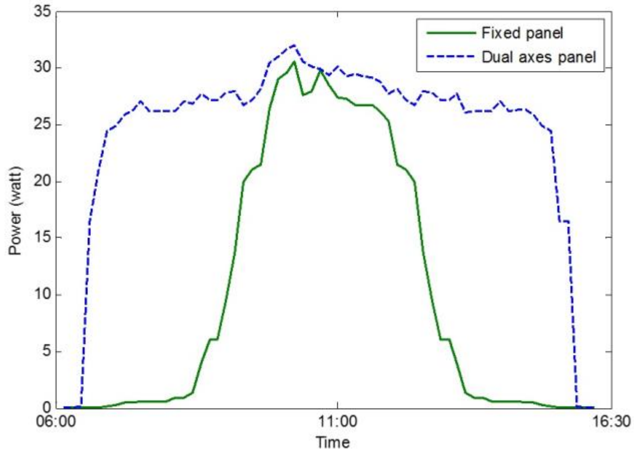

Fig. 10. The measured power from sunrise to sunset during the winter solstice for fixed solar panel and dual axes panel.

5. Conclusion

The PV panel is the future energy source. The maximum energy gained from PV panels is when the solar beam is perpendicular to it as the sun is moving one degree every four minutes and between year seasons. This study results showed improvement of the efficiency to almost double using dual axes tracking system in comparison to fixed PV panel, where an increasing of 76% and 41% have been recorded during the summer and winter solstice, respectively.

Acknowledgements

The authors wish to thank Al-Zaytoonah University of Jordan, Jordan for providing financial support for this research project.

References

[1] H. Hijazi, O. Mokhiamar, and O. Elsamni, “Mechanical design of a low-cost parabolic solar dish concentrator”, Alexandria Eng. J., vol. 55, pp. 1-11, 2016.

[2] A. Hafez, A. Yousef, and N. Harag, “Solar tracking systems: Technologies and trackers drive types – A review”, Renewable and Sustainable Energy Rev., vol. 91, pp. 754-782, 2018.

[3] R.A. Ferdaus, M.A. Mohammed, S. Rahman, S. Salehin, M. Abdul Mannan, “Energy efficient hybrid dual axis solar tracking system”, J. Renew. Energy, pp. 1-12, 2014.

[4] R.A. McFee, “Power collection reduction by mirror surface non flatness and tracking error for a central receiver solar power system”, Appl. Opt., vol. 14, pp. 1493-1502, 1975.

[5] R. Zogbi, and D. Laplaze, “Design and construction of a sun tracker”, Sol. Energy, vol. 33, pp. 369-72, 1984.

[6] S. Rumala, “A shadow method for automatic tracking”, Sol. Energy, vol. 37, pp. 245-247, 1986.

[7] A.J.N. Khalifa, and S.S. Al-Mutawalli, “Effect of two-axis sun tracking on the performance of compound parabolic concentrators”, Energy Convers. Manag., vol. 39, pp. 1073-1079, 1998.

[8] V. Poulek, “Testing the new solar tracker with shape memory alloy actors”, IEEE 1st World Conference on Photovoltaic Energy Conversion-WCPEC (A Joint Conference of PVSC, PVSEC and PSEC), pp. 1131-1133, December 1994.

[9] A. Gama, C. Larbes, A. Malek, F. Yettou, and B. Adouane, “Design and realization of a novel sun tracking system with absorber displacement for parabolic trough collectors”, J. Renew. Sustain. Energy, vol. 5, pp. 1-18, 2013.

[10] E.L. Peterson, and S.R. Gray, “Effectiveness of desalination powered by a tracking solar array to treat saline bore water”, Desalin., vol. 293, pp. 94-103, 2012.

[11] H. Tanaka, and Y. Nakatake, “One step azimuth tracking tilted-wick solar still with a vertical flat plate reflector”, Desalin., vol. 235, pp. 1-8, 2009.

[12] D. Zhao, E. Xu E, Z. Wang, Q. Yu, L. Xu, and L. Zhu, “Influences of installation and tracking errors on the optical performance of a solar parabolic trough collector”, Renew. Energy, vol. 94, pp. 197-212, 2016.

[13] B. Basnayake, W. Jayathilaka, Y. Amarasinghe, R.A. Attalage, and A. Jayasekara, “Smart solar tracking and on-site photovoltic efficiency measurement system”, Moratuwa Engineering Research Conference (MERCon), pp. 54-59, 5 Apr 2016.

[14] Y.K. Choi, I.S. Kim, S.T. Hong, and H.A. Lee, “A study on development of azimuth angle tracking algorithm for tracking-type floating photovoltaic system”, Adv. Sci. Technol. Lett., vol. 51, pp. 197-202, 2014.

[15] M.H.M, Sidek, W.Z.W. Hasan, M.Z. Kadir, S. Shafie, M.A.M. Radzi, and S.A. Ahmad, “GPS based portable dual-axis solar tracking system using astronomical equation”, IEEE International Conference Power Energy, pp. 245-249, 2014.

[16] H. Fathabadi, “Novel high accurate sensorless dual-axis solar tracking system controlled bymaximum power point tracking unit of photovoltaic systems”, Appl. Energy, vol. 173, pp. 448-459, 2016.

[17] M.F. El-Refaie, “Performance analysis of the stationary-reflector/ tracking-absorber solar collector”, Energy Convers. Manag., vol. 29, no. 2, pp. 163-189, 1989.

[18] J. Wu, H. Hou, and Y. Yang, “Annual economic performance of a solar-aided 600MW coalfired power generation system under different tracking modes, aperture areas, and storage capacities”, Appl. Therm. Eng., vol. 104, pp. 319-332, 2016.

[19] A. Cammarata, “Optimized design of a large-workspace 2-DOF parallel robot for solar tracking systems”, Mech. Mach. Theory, vol. 83, pp. 175-186, 2015.

[20] H. Zhong, G. Li, R. Tang, and W. Dong, “Optical performance of inclined south-north axis three positions tracked solar panels”, Energy, vol. 36, pp. 1171-1179, 2011.

[21] T. Hong, K. Jeong, C. Ban, J. Oh, C. Koo, and J. Kim, “A preliminary study on the 2axis hybrid solar tracking method for the smart photovoltaic blind”, Energy Procedia, vol. 88, pp. 484-490, 2016.

[22] A. Karima, A. Fekik, D. Hocine, M.L. Bakir, E. Bourennane, T.A. Malek, and A. Malek, "Improved performance of a PV solar panel with adaptive neuro fuzzy inference system ANFIS based MPPT", 7th international conference on renewable energy research and applications (ICRERA), pp. 1098-1101, 2018.

[23] H. Tchakounté, C.B. Fapi, M. Kamta, H. Djalo, and P. Woafo, "Performance comparison of an automatic Smart Sun tracking system versus a manual Sun tracking", 8th International Conference on Smart Grid (icSmartGrid), pp. 127-132, 2020.

[24] M.E. Shayan, and G. Najafi, "Energy-economic optimization of thin layer photovoltaic on domes and cylindrical towers." International Journal of Smart Grid vol. 3, no. 2, pp. 84-91, 2019.

[25] F. Javed, "Impact of Temperature & Illumination for Improvement in Photovoltaic System Efficiency." International Journal of Smart Grid- ijSmartGrid, vol. 10, pp. 23-28, 2022.

[26] Y.E. Abu Eldahab, N.H. Saad, and A. Zekry, "Assessing wind energy conversion systems based on newly developed wind turbine emulator." International Journal of Smart Grid-ijSmartGrid, vol. 4, no. 4, 2020.

[27] M.R. Tur, İ. Colak, and R. Bayindir, "Effect of faults in solar panels on production rate and efficiency", International Conference on Smart Grid (icSmartGrid), pp. 287-293, 2018.

[28] C. Jamroen, P. Komkum, S. Kohsri, W. Himananto, S. Panupintu, and S. Unkat, “A low-cost dual-axis solar tracking system based on digital logic design: Design and implementation”, Sustainable Energy Technolo. Assess., vol. 37, 100618, 2020.

[29] G. Wang, Y. Yao, B. Wang, and P. Hu, “Design and thermodynamic analysis of an innovative hybrid solar PV-CT system with multi-segment PV panels”,

Sustainable Energy Technolo. Assess., vol. 37, 100631, 2020.

[30] A. Awasthi, A. Kumar Shukla, M. Manohar, C. Dondariya, K.N. Shukla, D. Porwal, and G. Richhariya, "Review on sun tracking technology in solar PV system", Energy Rep., vol. 6, pp. 392-405, 2020.