Journal of Robotics and Control (JRC)
Volume 5, Issue 4, 2024
ISSN: 2715-5072, DOI: 10.18196/jrc.v5i4.19931

Unlocking Solar Potential: Advancements in Automated Solar Tracking Systems for Enhanced Energy Utilization

Abadal-Salam T. Hussain [1*], Baqer A Hakim [2], Saadaldeen Rashid Ahmed [3], Tareq Hamad Abed [4], Taha A. Taha [5], Taif. S. Hasan [6], Raed Abdulkareem Hasan [7], Abdulghafor Mohammed Hashim [8], Jamal Fadhil Tawfeq [9]
[1] Department of Medical Instrumentation Techniques Engineering, Technical Engineering College, Al-Kitab University, Altun Kupri, Kirkuk, Iraq
[2] College of Dentistry, University of Al-Ameed, Karbala PO Box 198, Iraq
[3] Computer Science Department, Bayan University, Erbil, Kurdistan, Iraq
[3] Artificial Intelligence Engineering Department, College of Engineering, Al-Ayen University, Thi-Qar, Iraq.
[4] Renewable Energy Research Centre, University of Anbar, Anbar, Iraq
[5, 7] Unit of Renewable Energy, Northern Technical University, Kirkuk, Iraq
[6] Department of Cyber Security and Cloud Computing, Al-Ma'moon University College, l-Washash, Baghdad, Iraq
[8] Al-Amarah University College, Engineering of Technical Mechanical Power Department, Maysan, Iraq
[9] Department of Medical Instrumentation Technical Engineering, Medical Technical College, Al-Farahidi University, Baghdad, Iraq
Email: [1] asth2233@gmail.com, [2] ahmosawi@alameed.edu.iq, [3] saadaldeen.aljanabi@bnu.edu.iq, [4] tarek.hamd@uoanbar.edu.iq, [5] t360pi@gmail.com, [6] taif.s.hasan@almamonuc.edu.iq, [7] raed.isc.sa@ntu.edu.iq, [8] abd.ghafoor@alamarahuc.edu.iq, [9] jamaltawfeq55@gmail.com
*Corresponding Author

Abstract—**The use of solar tracking systems has become vital and has established itself as a vital element in the generation of solar energy by enhancing the collection efficiency. This paper seeks to understand the necessity of shifting from conventional energy sources and why issues like scarcity of fossil fuel, and pollution are some of the hurdles toward achieving sustainable energy. Solar power, in particular, is one of the lights at the end of this tunnel since it pioneers a shift towards the usage of clean energy in the world. The subject of interests of the study is on how tracking systems help in maximizing energy collection from solar systems by interchanging it with the movement of sun's path. It discusses the method that was followed, which involves selecting component, designing circuit and developing software together with presenting empirical data that was obtained from a three-day, Twenty-four-hour experiment. Outcomes show that there is an improvement on voltage stability, the level of solar irradiation and temperature regulation when the system is applied as compared to static system and its applicability for the enhancement of the renewable energy harnessing methods by using the solar tracking technology. Finally, it outlines the future research directions to continue exploring the proposed methods and its wider impact on renewable energy generation.**

Keywords—Solar Energy; Photovoltaic Technology; Solar Tracking; Renewable Energy; Efficiency Enhancement.

I. INTRODUCTION

Energy consumption worldwide continues to be in a state of transition due to the pressure to adopt efficiency and the utilization of clean sources of energy. While the global communities demand green energy, power for electric appliances through the reduction on the use of fossil fuel, power pollution and the global search for ways to fight climate change Solar Power stands as a hope of a dry land. Solar technology harnesses what is indefinitely available in the world, which is light and heat from the sun thus making it possible amongst the cleanest and most renewable sources of energy that could be used to produce electricity [1]-[5].

Therefore, one of the prime solutions that has emerged out of all these is the use of automated solar tracking systems since it will go a long way to enhancing the process by way of energy capture from the sun. However, for the sake of clarity, the set of characteristics that do not allow any adjustments and usually denote the standard, non-rotational solar panels by which the station is equipped upon arrival are specifically called the static systems [24]-[26]. T his paper aims at studying and analyzing the possible use of the automated solar tracking systems in improving the practices of energy conversion and encouraging the utilization of renewable energy technology.

This work begins with an exploration of why there has been a push toward renewable energy forms and Cortazar & Ovalle (2014) assertion on the integral role solar energy. The next section is on implementation with the specifications namely for the selection of the components, circuits and programming required for the solar tracking system [9]-[14]. The details collected scientifically through factual numbers are then used to make comparisons between the first three days of the intensive study in terms of the stability range of the system's run in voltage, amount of insolation, and temperature.

Even though the technology of solar power has advanced and is advancing constantly within the recent years and the modern farm of solar panels is developing rapidly, it has a drawback that they have two axes, therefore, they cannot follow the path of the sunshine at different times of a day.

This has created limitations in the tracking of the sunlight, whose solution has been to develop Automated solar tracking systems that tracks the sun and orients the solar panels appropriately. But, as you know that need further research in certain high and their dynamics and their further improvement according to prior studies [15]-[17].

The main objective of this work, therefore, is to find out if the utilization of an automated tracking system of the sun is feasible and can lead to a substantial increase in the generation and conversion efficiency of photovoltaic modules in solar configuration. Its is quite informative especially in the last three sections recommending the component to be used in the tracking, the circuits that ought to be employed in the construction of the solar tracker and also the program that should be written in the microcontroller, as well as data acquisition section. In conclusion, this work also highlights the relevance of the automated solar tracking systems as an instrument which can possibly bring a rather radical improvement to the further development of the utilization of the fresh sources of electrical energy and add a fresh impulse to the contemporary global environmental shift towards the clean methods of the electricity production [18]-[25].

Results from the study demonstrate the effectiveness of the automated solar tracking system in maximizing energy capture and enhancing system efficiency compared to static solar panels [26]-[33]. The paper concludes by discussing the broader implications of solar tracking technology for renewable energy generation and outlining potential avenues for future research. Overall, the study contributes to advancing our understanding of solar energy technology and its role in fostering a more sustainable and environmentally conscious future [34]-[38].

II. METHODOLOGY

In the methodology section, a comprehensive approach was undertaken, beginning with the meticulous selection of components such as the PIC16F877A microcontroller, Light Dependent Resistors (LDRs), DC motor, and voltage regulators, followed by the development and optimization of circuit designs including the main circuit board, motor driver circuit, power supply circuit, solar charger circuit, and sensor circuit using Proteus software, alongside the programming of the microcontroller in the C language to enable precise control and real-time feedback, further integrating the motor driver circuit to dynamically adjust the solar panel orientation based on sunlight intensity detected by the sensors, alongside the integration of the power supply circuit to ensure stable voltage distribution to all system components, including both 12V and 5V outputs for seamless functionality, coupled with the incorporation of the solar charger circuit to regulate charging and prevent overcharging of the battery, while managing the charging process based on input voltage from the solar panel, and deploying the sensor circuit featuring LDRs to continuously monitor sunlight intensity, thereby enabling precise sun tracking and adjustments in solar panel orientation, ultimately facilitating the successful development, implementation, and evaluation of the automated solar tracking system and providing valuable insights into its performance and potential for enhancing renewable energy generation.

The depiction reveals an exhaustive programming flowchart intricately delineating the step-by-step functioning of the automated solar tracking system, which ingeniously integrates four strategically positioned Light Dependent Resistors (LDRs) atop the solar panel, facilitating perpetual assessment of sunlight intensity; initiating with a pivotal initialization phase configuring crucial parameters and variables, the system centrally hinges upon the astute juxtaposition of sensor data, promptly activating a motor upon detecting inconsistencies in sunlight intensity sensed by the LDRs, indicative of suboptimal solar panel alignment, thus dynamically realigning the solar panel to ensure uniform light intensity across all LDRs, a critical process paramount for maximizing solar energy capture; concurrently, a user-friendly LCD display furnishes real-time insights into solar intensity, facilitating performance assessment, while upon precise alignment with the sun, the solar panel embarks on its vital task of converting solar energy into electrical power, with a portion intelligently channeled to a solar charger adeptly regulating voltage from the panel to charge a battery, serving as a pivotal energy reservoir during periods of diminished sunlight, vigilantly monitored by another LCD screen displaying battery voltage, thus ensuring continuous holistic operation seamlessly adapting to sunlight fluctuations and consistently maximizing solar energy utilization; fundamentally, this automated solar tracking system represents an innovative solution unlocking the full potential of solar resources, its adaptability and efficacy in energy capture rendering it indispensable in sustainable energy generation, heralding a greener and more efficient era of power production.

Its function revolves around its ability to rotate the motor in such a way that differents light-dependent resistors sample similar relations of light from the solar panel. This should be done to maximize the conversion of the heat from sun to energy because we notice that the Solar Panel has to be in the correct position due to the movement of the sun throughout the day. Also, an LCD display plays an important role in evaluating the original strength of the source of energy, that is, the sun or solar irradiance so that the users or system patrons will be in a position to monitor the performance of the system. When, mount of the solar panels, aligns towards the sun, the solar panels change the solar energy into electrical energy.

A portion of the created power is delivered to a solar charger that has the option to regulate the charge voltage of the supplied power from the solar panel. Foremost, a solar charger is meant to charge a battery, which is an important component of power supply system and a storage tool of extra power; specially when the direct sunlight is not sufficient – say at night or during winter. Another LCD screen monitors the battery voltage to make sure that the batteries are charging or charged to the right voltage. This is an ongoing process that works fine, and additionally, it always responds to the changes in the level of irradiation: they ensure the collection of the maximum amount of available solar energy all the time. Therefore, the detailed above automated solar tracking system increases the offer of solar resources, which makes it an effective instrument for successful solar power distribution.

A. Automatic Solar Tracking System Basic Idea

This is also a detailed project on automatic solar tracking with many components involved including a microcontroller required both in the software and in the hardware domain. That the hardware components, as displayed, making up part of aspects that are inevitable to the formation of the system. This makes it possible to make a further detailed analysis of the system's workings as illustrated in the block diagram herein above. Here the sensor is a sensitive component that is mainly expected to determine the position of the sun, which ordinarily helps provide feedback that's instrumental in ascertaining the relative position of the sun towards the solar tracking process. Solar panel which is made up of cells helps in obtaining a Direct Current voltage out of solar energy. In this process, the sensor is programmed in a manner that if any form of light or direct sun rays are in contact with the panel, the motor is activated to rotate the panel to ensure that its surface area is as much exposed to the sun as possible.

This dynamic motion enhances energy retrieval, resulting in heightened power generation throughout daylight hours. Furthermore, a solar charger refills the battery, capturing voltage from the solar panel and proficiently stockpiling the generated energy for subsequent usage. A built-in LCD monitors the battery's condition and the charging procedure, offering immediate feedback to the user. The microcontroller analyzes this information and, guided by the sun's position, triggers the motor to reorient the solar panel. This active adjustment guarantees maximal exposure to sunlight, optimizing energy collection. The solar charger efficiently harnesses the panel's voltage to charge the battery, ensuring effective energy retention. An integrated LCD furnishes real-time updates on the battery's condition and the charging sequence.

B. Circuit Design

Main Circuit Board Design: Utilizing Proteus software, the main circuit board's design was meticulously crafted. The schematic Fig. 1 and PCB layout Fig. 3 were optimized for functionality and reliability. Motor Driver Circuit: The motor driver circuit was developed to interface with the microcontroller and control motor movement. The schematic Fig. 2 and PCB layout Fig. 4 are presented for clarity. Power Supply Circuit: The power supply circuit was designed to deliver stable voltage to various components. Detailed specifications of voltage regulators and overvoltage/overcurrent protection mechanisms are included. ISIS schematic main circuit design solar Charger Circuit: Responsible for regulating charging and safeguarding the battery against overcharging, the solar charger's components and roles are detailed. Sensor Circuit: LDRs were employed in the sensor circuit to detect sunlight and contribute to precise sun tracking. The circuit's design, LDR placement, and role in tracking are explicated.

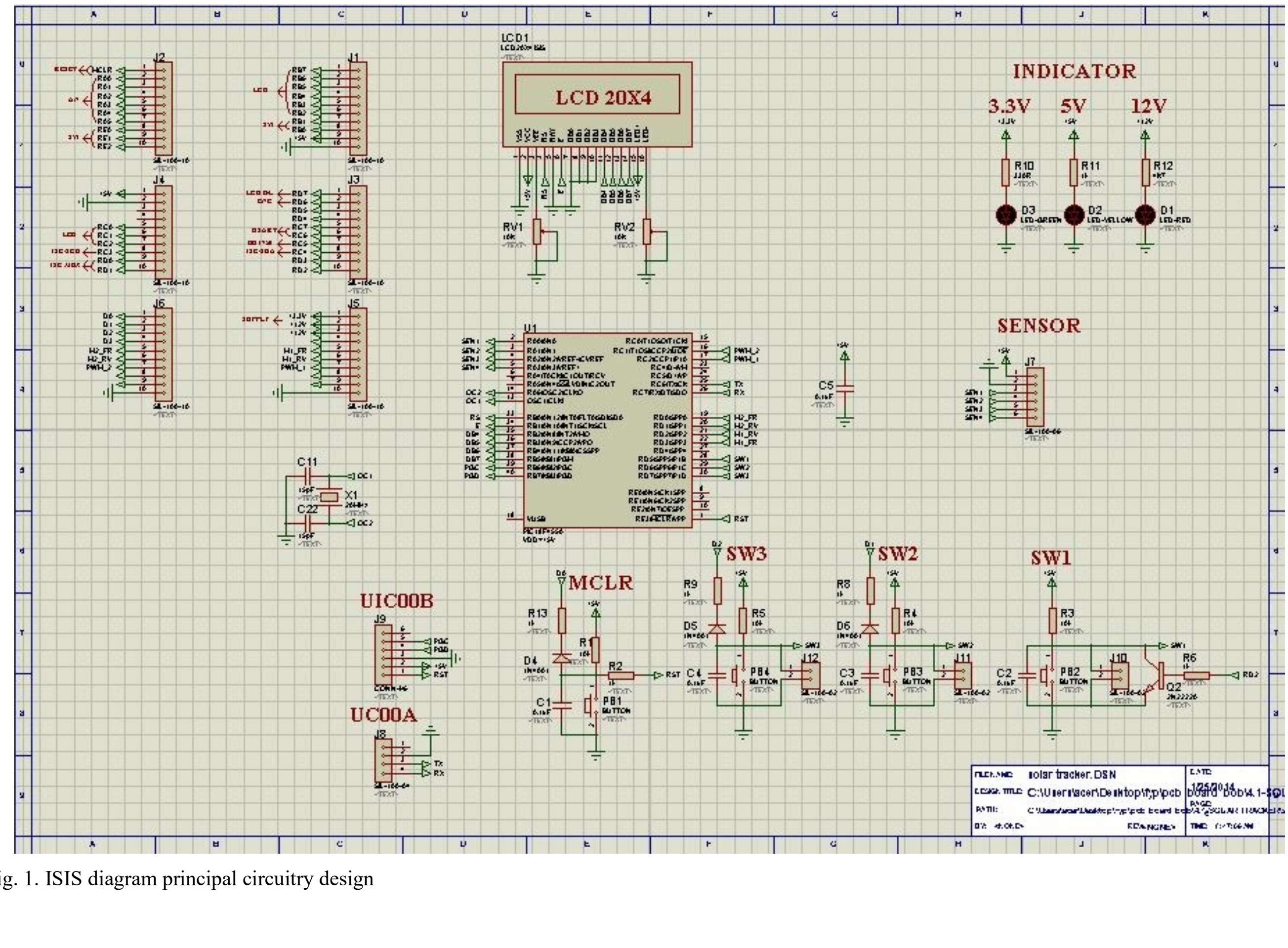

Fig. 1. ISIS diagram principal circuitry design

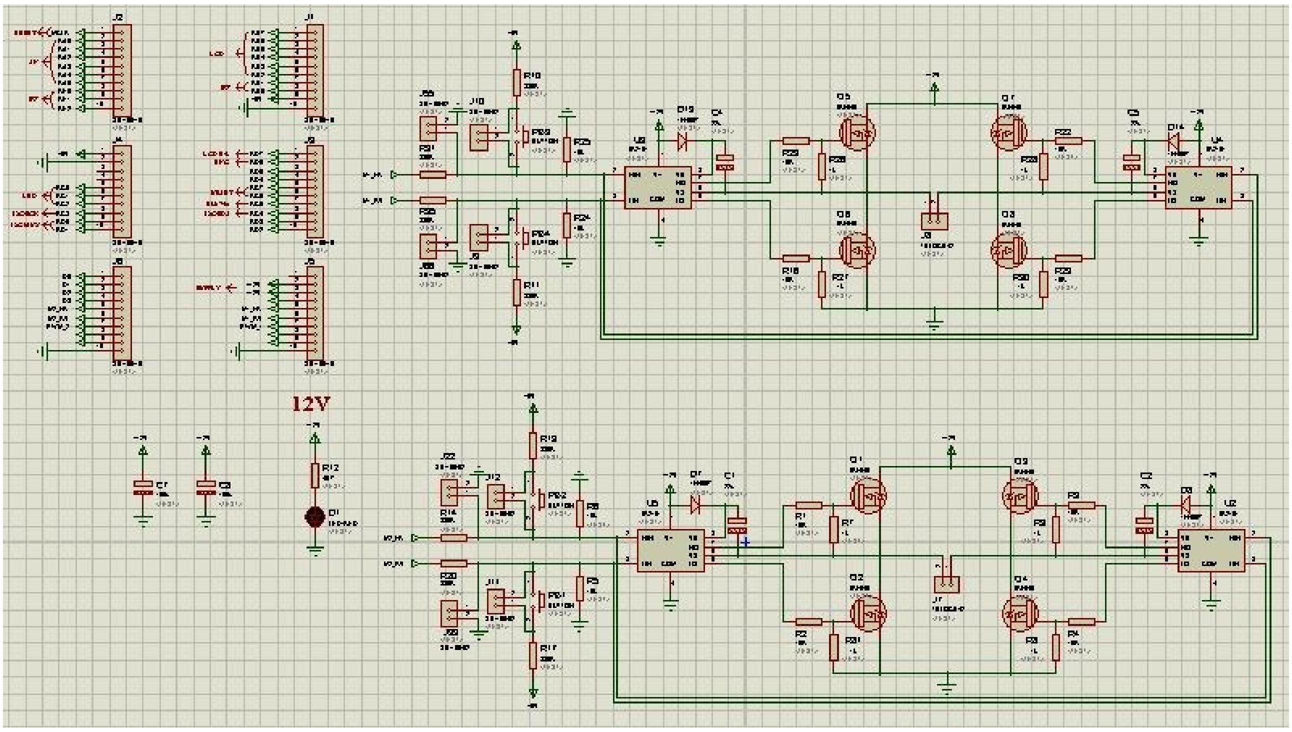

Fig. 2. Motor controller diagram layout

C. *Software Development*

The project's programming aspect involved: Programming Language: The C language was utilized to code the microcontroller, offering precise control and real-time feedback. Algorithms: Detailed algorithms for sun tracking and motor control.

D. *Motor Driver Circuit Design*

The automatic solar tracking system uses a circuit with a motor driver to control the DC motor's movement as shown in Fig. 5. Once the microcontroller gets the signal to move the motor, it activates the motor driver, which then powers the DC motor as shown in Fig. 6. The sensor detects sunlight and sends a signal to the microcontroller to initiate movement as shown in Fig. 6.

E. *Power Supply Circuit Design*

The power distribution circuit has been meticulously designed to ensure that each component receives an adequate and steady voltage supply, this power source is versatile, capable of delivering both 12 volts and 5 volts as its output. The 12V power supply plays a pivotal role in energizing the motor driver, depicted, which, in turn, facilitates the movement of the motor. On the other hand, the 5V power supply is dedicated to powering the other circuit boards, as depicted, contributing to their proper and seamless functionality. The power supply board stands out as a critical component within the system, serving as the cornerstone for delivering dependable and precisely regulated power. This ensures the efficient and uninterrupted operation of all interconnected circuits, as documented in reference [39]-[45].

F. *Solar Charger Circuit Design*

The central role of the solar charger revolves around harnessing solar panel-generated power to charge batteries. This pivotal component is intricately linked to a microcontroller, as visually depicted in Fig. 3. A notable feature of this charger is its intelligent control system: it ceases the charging process when the battery reaches full capacity and resumes when necessary, ensuring the battery remains primed to supply power to the motor. The solar charger board assumes the crucial task of regulating the charging voltage, constantly monitoring the input voltage from the solar panel during the charging operation, as illustrated in Fig. 3. It goes a step further by safeguarding the battery against overcharging. Notably, an LCD screen, showcased in Fig. 4, is integrated into the solar charger, displaying the voltage level throughout the charging cycle.

G. *Sensor Circuit Design*

In the sensor circuit, Light Dependent Resistors (LDRs) are used as sensors. Four LDRs are incorporated into this circuit to detect sunlight as shown in Fig. 7. These sensors send signals to the main board, which then activates the motor to adjust the solar panel's position based on the detected sunlight as shown in Fig. 7. The LDRs enable precise sun tracking, ensure optimal solar energy utilization, and enhance the overall system's performance [46]-[51]. The autonomous solar tracking system's capacity to detect and react to sunlight is due in large part to the sensor circuit, as shown in Fig. 8.

This circuit makes use of the Light Dependent Resistors' (LDRs') abilities, which act as the system's solar eyes. On the solar panel, four LDRs that are carefully positioned keep an eye on the incoming sunlight all the time from different directions. LDRs have the unusual characteristic that their resistance changes depending on the amount of light they are exposed to. These sensors' degrees of resistance alter in response to sunlight [52]-[58].

Their performance in the sensor circuit is based on this characteristic as shown in Fig. 8. The main board, which commonly houses a microcontroller functioning as the system's central processing unit, receives the electrical impulses produced by the LDRs in response to changing light levels. This main board is where the system's data is processed. The microcontroller is essential for deciphering the incoming data and determining the precise location of the solar panel. The microprocessor starts an operation if the LDRs detect variations in sunlight intensity, indicating that the solar panel is not perfectly aligned with the sun. This is accomplished by turning on a motor, which is crucial in changing the solar panel's orientation [59]-[61]. The solar panel should always face the direction the sun is facing in the sky to maximize solar energy absorption. The microprocessor and LDRs' capacity to track the sun precisely and dynamically is essential for improving the performance of the entire system [62]-[64]. This system increases its efficiency and capacity for power generation by continuously adjusting the angle of the solar panel in response to shifting sun positions throughout the day. The designed circuit PCB structure of all the circuits described above is given in Fig. 9.

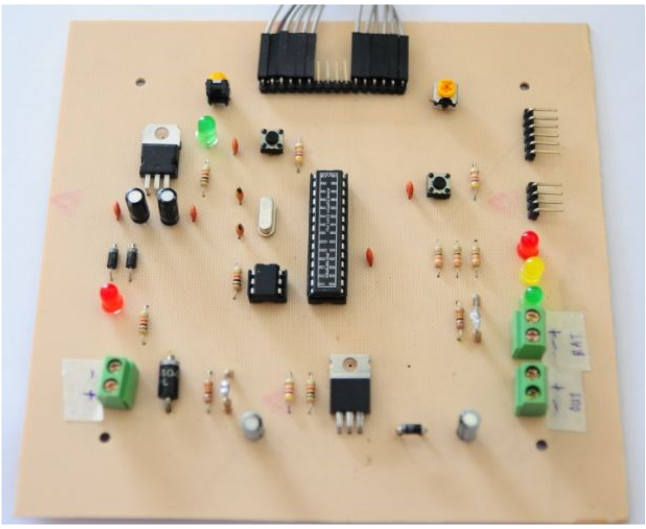

Fig. 3. Solar converter PCB configuration

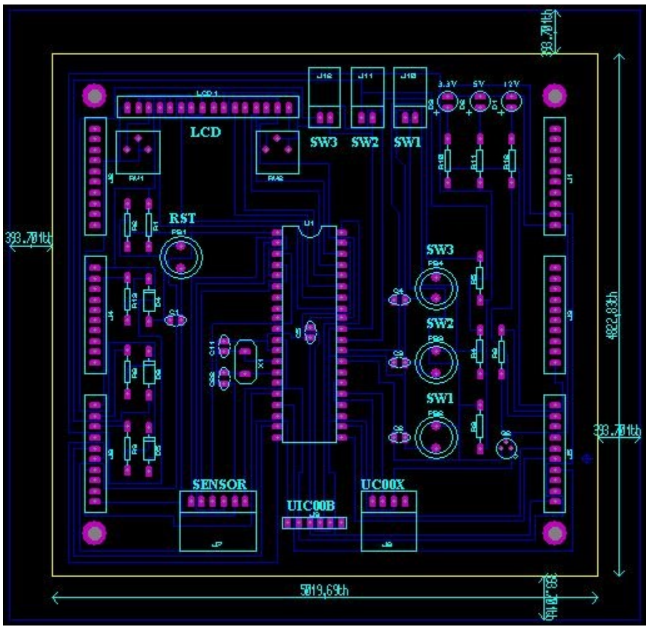

Fig. 4. Drive mechanism panel

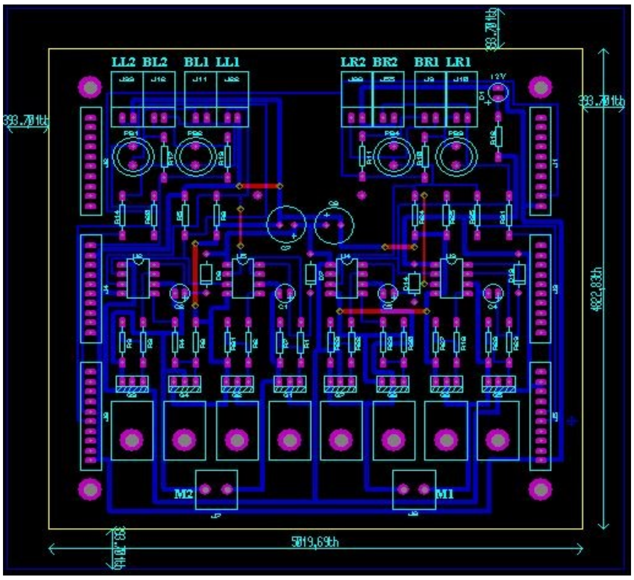

Fig. 5. Drive mechanism PCB arrangement

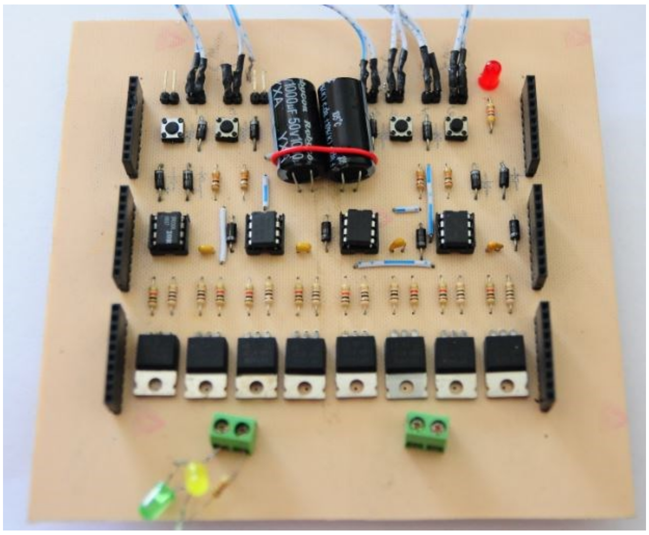

Fig. 6. Photovoltaic charging board

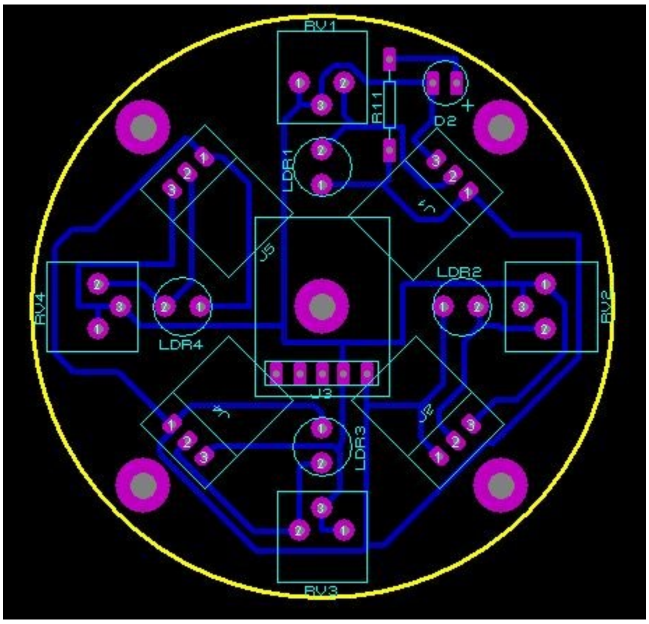

Fig. 7. Sensor module PCB arrangement

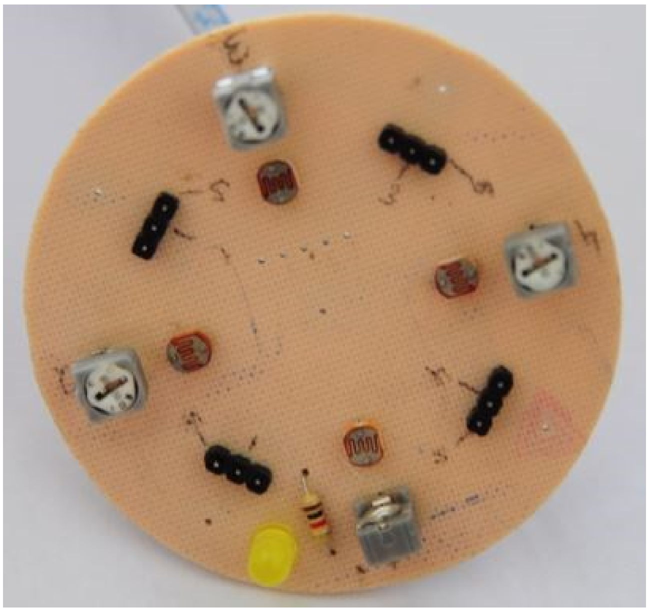

Fig. 8. Detection circuit board

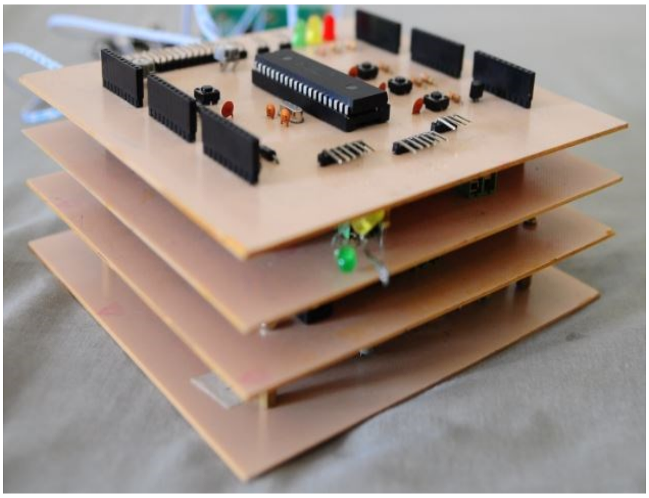

Fig. 9. Total solar alignment circuit design

III. Results

The actual experiment contributes significantly into the understanding of the effectiveness of running the business with the automated solar tracking system: alone, is solely essential for evaluating the efficiency of the system in terms of deriving the optimum usage of solar power. In this part of the document we also make sure that the findings are depicted and analyzed coherently as well as devote attention to primary issues and consequences. More specifically, is the case of the solar tracking system; the steady control of voltage is unique as evident by the ac cycle diagram outlined in Fig. above in this regard, voltage control ranges between 18V and 20V. This praiseworthy achievement will go to prove how the system is able to make energy production to be decentralized and also provide constant energy output this is especially true especially weather changes which may be very crucial in ensuring that dependent and efficient energy is being produced continues to be provided.

Through data scrutiny, our analysis unveils that our solar tracking system consistently outperforms static counterparts in receiving heightened solar irradiance levels, as illustrated in Fig. 9. Notably, the peak irradiance attained by our tracking system peaks at 1555 W/m², markedly surpassing the 1460 W/m² achieved by static solar systems. This substantial disparity in irradiance levels serves as a testament to the effectiveness of our solar tracking system in optimizing solar energy absorption, thereby directly contributing to augmented electricity generation. It's imperative to recognize the significant influence of solar irradiance on voltage output, wherein elevated irradiance levels not only bolster energy generation but also impact the efficiency of solar panels. Nevertheless, it's noteworthy that excessively high solar irradiance levels can curtail the longevity of solar panels and diminish overall efficiency. Hence, the commendable ability of our system to sustain heightened irradiance levels without veering into detrimental extremes represents a noteworthy achievement.

The superior temperature control exhibited by our system is of practical significance Fig. 7. By ensuring that the solar panel operates within an optimal temperature range, our technology prolongs panel lifespan and maintains efficiency. This achievement aligns with broader research on solar tracking technology, which anticipates enhanced temperature control as one of the technology's benefits. While direct comparisons with other studies remain challenging due to the uniqueness of our system, it's valuable to provide some context (See Fig. 10, Fig. 11, Fig. 12, Fig. 13, and Fig. 14). Existing research in the field has also highlighted the benefits of solar tracking technology, including enhanced temperature control, higher irradiance levels, and improved voltage stability. Our results align with these anticipated advantages, reinforcing the value of solar tracking technology in solar energy production. Acknowledging the importance of a balanced perspective, it's essential to discuss potential limitations and practical implications (See Fig. 10, Fig. 11, Fig. 12, Fig. 13, and Fig. 14). While our system demonstrated remarkable performance, it's crucial to acknowledge that specific conditions may affect its optimal operation. In extreme weather or unforeseen circumstances, the system may face challenges. This is crucial as it will help in enabling a correct assessment of the wave of the application of the technology in question.

Therefore, future research directionality is important in an examination of quality improvement and succession in an effort to attain the quality recognized in other countries. Other similar future studies may then contrast our developed system with other solar tracking techniques in order to come up with a comparison of the two. As for the applicability of what we have manifested in terms of technology for other climate zones and regions, broadening the scope of its application can provide additional awareness of how diverse it is.

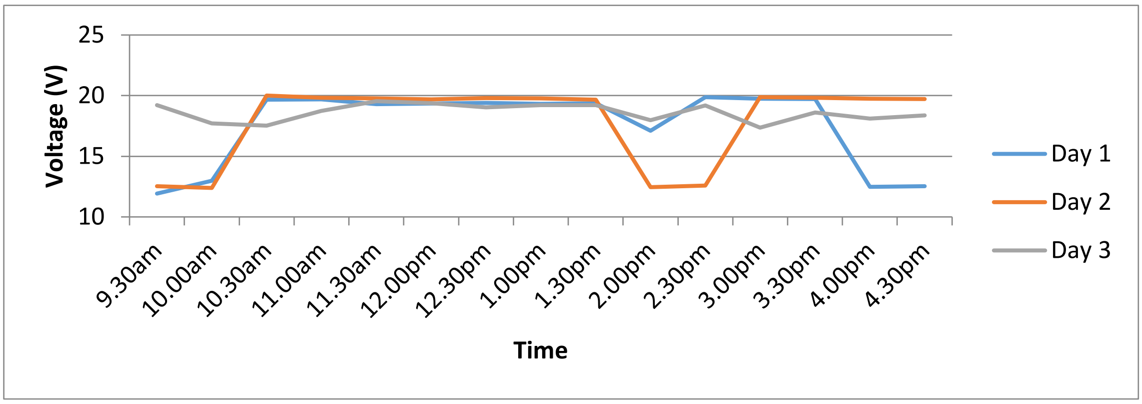

Fig. 10. Solar static voltage measurements

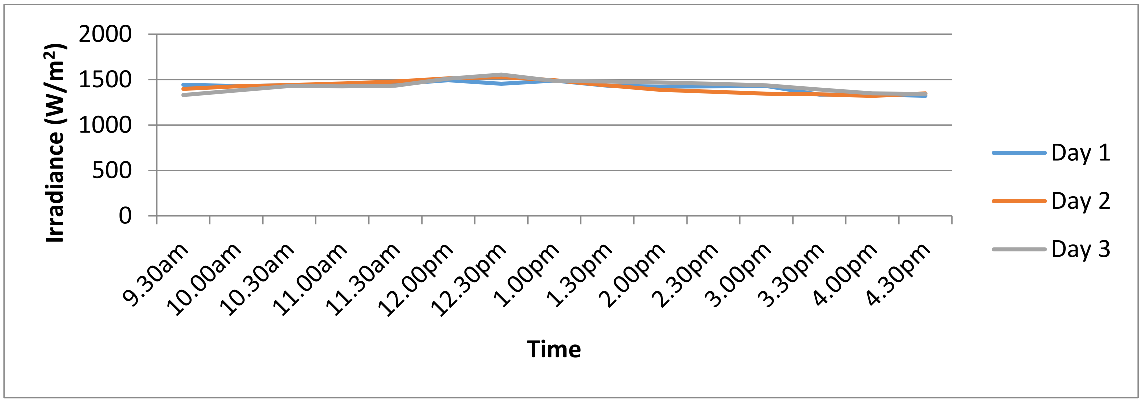

Fig. 11. Data on solar tracker sunlight intensity

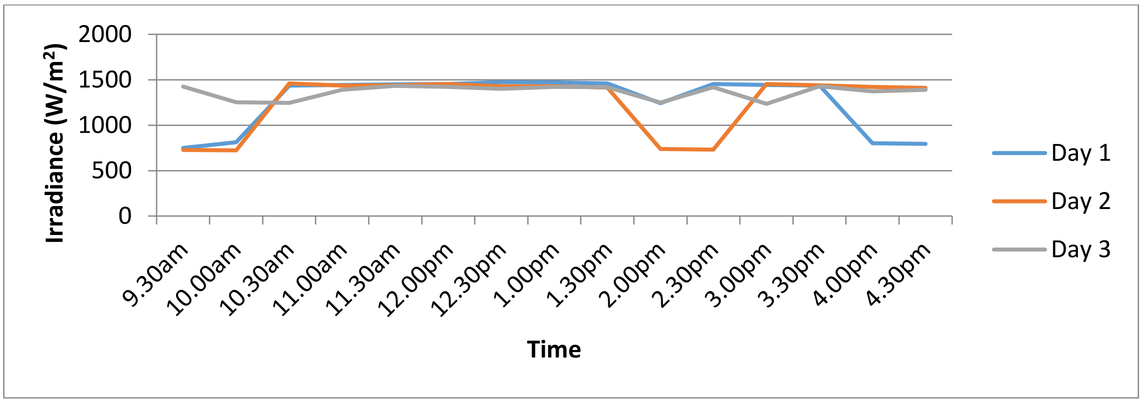

Fig. 12. Data on solar tracker sunlight exposure

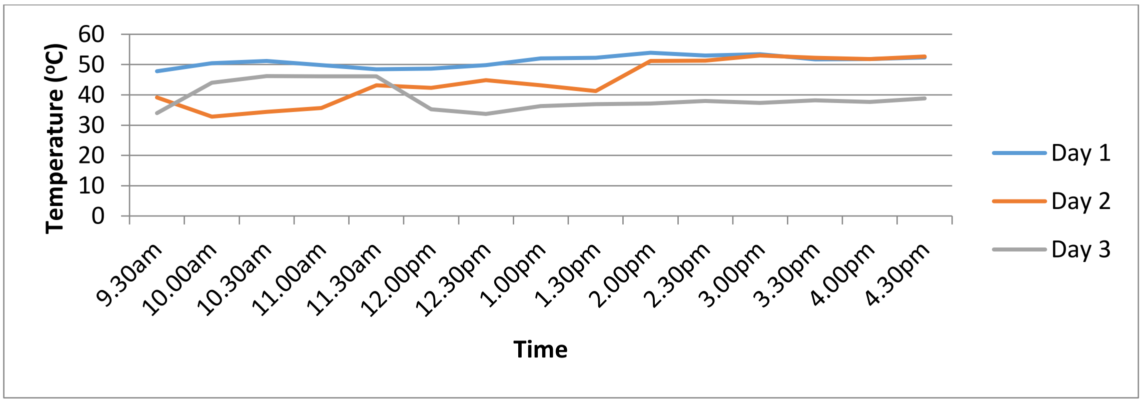

Fig. 13. Data on solar tracker thermal conditions

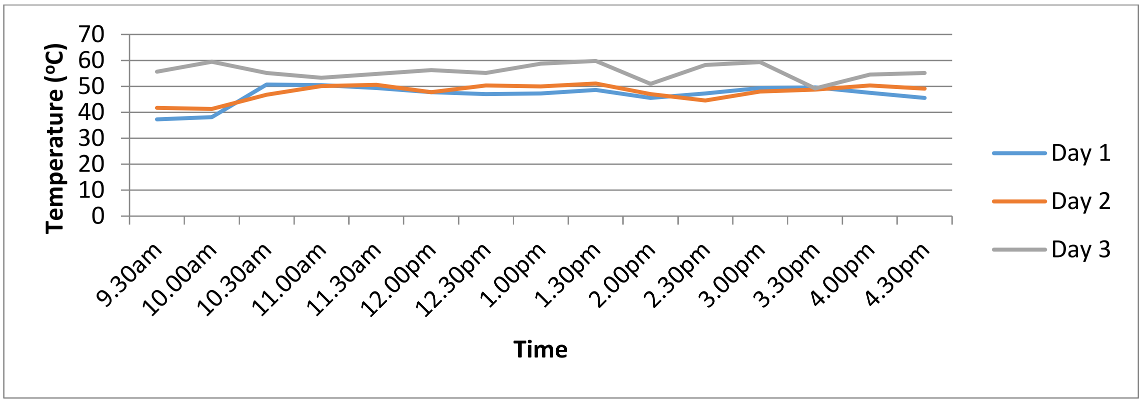

Fig. 14. Data on stationary solar temperatures

IV. Conclusion

Finally, this research has shown how other methods of solar tracking have the capacity of enhancing the efficiency of solar energy use through provision of relevant data on how effective those means are in its operations and functionality. A lot of care has therefore been taken in experimenting and researching for the fact that we supply stable and perfect voltage which in turn gives assurance of generating brilliant power by enhancing absorption of irradiance in so doing producing electricity from solar power. The study has shown the much needed use of the high tech solar tracking to improve the nature and efficiencies of solar energy converting systems. Furthermore, realizing that more irradiance is good, yet possibly bad, when determined by the amount of irradiation that solar panels absorb adds to the present contribution. However, it seems reasonable to list some of the improvements concerning the further development of the concept, and key issues, such as the potential adaptability and versatility of the automated tracking systems in different conditions and territories. In conclusion, increased research of the outlined subject and increased efforts in the development of the technology described in this paper can prove useful in improving on the promotion of sustainable energy solutions which would steer the world towards a cleaner and more efficient energy system in the future.

V. References

[1] J. E. G. Baquero and D. B. Monsalve, "From fossil fuel energy to hydrogen energy: Transformation of fossil fuel energy economies into hydrogen economies through social entrepreneurship," *International Journal of Hydrogen Energy*, vol. 54, pp. 574-585, 2023.

[2] S. Vijayalakshmi, S. Savita, and P. Durgadevi, "AI and IoT in Improving Resilience of Smart Energy Infrastructure," in *AI-Powered IoT in the Energy Industry: Digital Technology and Sustainable Energy Systems*, pp. 189-213, 2023.

[3] O. J. Olujobi, U. E. Okorie, E. S. Olarinde, and A. D. Aina-Pelemo, "Legal responses to energy security and sustainability in Nigeria's power sector amidst fossil fuel disruptions and low carbon energy transition," *Heliyon*, vol. 9, no. 7, 2023.

[4] H. Zhao, C. Wu, and Y. Wen, "Determinants of Corporate Fossil Energy Assets Impairment and Measurement of Stranded Assets Risk," *Energies*, vol. 16, no. 17, p. 6340, 2023.

[5] O. Hamilton, D. Nyberg, and V. Bowden, "Elements of power: Material-political entanglements in Australia's fossil fuel hegemony," *Environment and Planning E: Nature and Space*, vol. 6, no. 4, pp. 2295-2317, 2023.

[6] L. Gao. *A Dual Approach for Water Purification Based on Solar Energy*. Doctoral dissertation, Université Gustave Eiffel, 2022.

[7] M. K. G. Deshmukh, M. Sameeroddin, D. Abdul, and M. A. Sattar, "Renewable energy in the 21st century: A review," *Materials Today: Proceedings*, vol. 80, pp. 1756-1759, 2023.

[8] A. Rahman, R. Richards, P. Dargusch, and D. Wadley, "Pathways to reduce Indonesia's dependence on oil and achieve longer-term decarbonization," *Renewable Energy*, vol. 202, pp. 1305-1323, 2023.

[9] T. Wang, M. Umar, M. Li, and S. Shan, "Green finance and clean taxes are the ways to curb carbon emissions: An OECD experience," *Energy Economics*, vol. 124, p. 106842, 2023.

[10] A. M. Soodmand *et al*., "A comprehensive review of computational fluid dynamics simulation studies in phase change materials: applications, materials, and geometries," *Journal of Thermal Analysis and Calorimetry*, pp. 1-50, 2023.

[11] M. Z. Anam, A. M. Bari, S. K. Paul, S. M. Ali, and G. Kabir, "Modelling the drivers of solar energy development in an emerging economy: Implications for sustainable development goals," *Resources, Conservation & Recycling Advances*, vol. 13, p. 200068, 2022.

[12] J. A. Silva, "Wastewater Treatment and Reuse for Sustainable Water Resources Management: A Systematic Literature Review," *Sustainability*, vol. 15, no. 14, p. 10940, 2023.

[13] C. Y. Lin, K. Y. Chau, T. K. Tran, M. Sadiq, L. Van, and T. T. H. Phan, "Development of renewable energy resources by green finance, volatility and risk: empirical evidence from China," *Renewable Energy*, vol. 201, pp. 821-831, 2022.

[14] Q. Wang *et al*., "Biogas generation from biomass as a cleaner alternative towards a circular bioeconomy: Artificial intelligence, challenges, and future insights," *Fuel*, vol. 333, p. 126456, 2023.

[15] T. A. Taha, H. I. Zaynal, A. S. T. Hussain, H. Desa, and F. H. Taha, "Definite time over-current protection on transmission line using MATLAB/Simulink," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 2, pp. 713-723, 2024.

[16] J. Khan and M. H. Arsalan, "Solar power technologies for sustainable electricity generation–A review," *Renewable and Sustainable Energy Reviews*, vol. 55, pp. 414-425, 2016.

[17] S. K. Kar, A. S. K. Sinha, S. Harichandan, R. Bansal, and M. S. Balathanigaimani, "Hydrogen economy in India: A status review," *Wiley Interdisciplinary Reviews: Energy and Environment*, vol. 12, no. 1, p. e459, 2023.

[18] T. H. Oh, S. Y. Pang, and S. C. Chua, "Energy policy and alternative energy in Malaysia: Issues and challenges for sustainable growth," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 4, pp. 1241-1252, 2010.

[19] F. Zhang, J. Lu, and L. Chen, "When green recovery fails to consider coal pushback: Exploring global coal rebounds, production, and policy retrenchment post Covid-19," *Energy Research & Social Science*, vol. 101, p. 103142, 2023.

[20] C. M. S. Kumar *et al*., "Solar energy: A promising renewable source for meeting energy demand in Indian agriculture applications," *Sustainable Energy Technologies and Assessments*, vol. 55, p. 102905, 2023.

[21] A. O. Maka and J. M. Alabid, "Solar energy technology and its roles in sustainable development," *Clean Energy*, vol. 6, no. 3, pp. 476-483, 2022.

[22] Q. Liu and J. Sun, "Tripartite Evolutionary Game of Power Generation Enterprises' Green Transformation under the Responsibility Assessment of Renewable Energy Consumption in China," *Sustainability*, vol. 15, no. 13, p. 10512, 2023.

[23] T. Feng, R. Xiong, and P. Huan, "Productive use of natural resources in agriculture: The main policy lessons," *Resources Policy*, vol. 85, p. 103793, 2023.

[24] A. Rehman *et al*., "Globalization and renewable energy use: how are they contributing to upsurge the CO2 emissions? A global perspective," *Environmental Science and Pollution Research*, vol. 30, no. 4, pp. 9699-9712, 2023.

[25] S. Dey, A. Sreenivasulu, G. T. N. Veerendra, K. V. Rao, and P. A. Babu, "Renewable energy present status and future potentials in India: An overview," *Innovation and Green Development*, vol. 1, no. 1, p. 100006, 2022.

[26] I. Dincer and M. I. Aydin, "New paradigms in sustainable energy systems with hydrogen," *Energy Conversion and Management*, vol. 283, p. 116950, 2023.

[27] V. K. Sharma *et al*., "Imperative role of photovoltaic and concentrating solar power technologies towards renewable energy generation," *International Journal of Photoenergy*, vol. 2022, 2022.

[28] P. Ganesan and S. Gunasekaran, "Modelling and Simulation of Incremental Conductance Algorithm for Solar Maximum Power Point Tracker," in *2022 IEEE Delhi Section Conference (DELCON)*, pp. 1-6, 2022.

[29] J. L. Holechek, H. M. Geli, M. N. Sawalhah, and R. Valdez, "A global assessment: can renewable energy replace fossil fuels by 2050?," *Sustainability*, vol. 14, no. 8, p. 4792, 2022.

[30] P. E. Brockway, A. Owen, L. I. Brand-Correa, and L. Hardt, "Estimation of global final-stage energy-return-on-investment for fossil fuels with comparison to renewable energy sources," *Nature Energy*, vol. 4, no. 7, pp. 612-621, 2019.

[31] A. S. T. Hussain, D. Z. Ghafoor, S. A. Ahmed, and T. A. Taha, "Smart inverter for low power application based hybrid power system," in *AIP Conference Proceedings*, vol. 2787, no. 1, 2023.

[32] M. C. Udeagha and N. Ngepah, "Achieving decarbonization goals in BRICS economies: Revisiting the joint role of composite risk index, green innovation, and environmental policy stringency," *Cogent Social Sciences*, vol. 9, no. 1, p. 2234230, 2023.

[33] M. I. Khan and S. G. Al-Ghamdi, "Hydrogen economy for sustainable development in GCC countries: A SWOT analysis considering current situation, challenges, and prospects," *International Journal of Hydrogen Energy*, vol. 48, no. 28, pp. 10315-10344, 2023.

[34] N. V. Parasnis and A. P. Tadamalle, "Automatic solar tracking systems," *International Journal of Innovations in Engineering Research and Technology*, vol. 3, no. 1, pp. 1-8, 2016.

[35] D. Chettri, A. K. Verma, and A. K. Verma, "Exploring the potential of microalgae cell factories for generation of biofuels," *Biofuels*, vol. 15, no. 3, pp. 245-257, 2023.

[36] R. Kumar and R. Verma, "Design and implementation of an automatic solar tracking system using arduino," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 7, no. 1, pp. 360-366, 2018.

[37] O. K. Ahmed, S. Algburi, M. A. Jasim, T. A. Taha, A. M. Saleh, and K. F. Yassin, "Experimental assessment of the effect of black dye and water depth on the performance of PV/solar distiller," *Desalination and Water Treatment*, vol. 318, p. 100317, 2024.

[38] T. A. Taha, A. S. T. Hussain, and K. A. Taha, "Design solar thermal energy harvesting system," in *AIP Conference Proceedings*, vol. 2591, no. 1, 2023.

[39] H. R. Bohlmann, J. A. Bohlmann, M. Chitiga-Mabugu, and R. Inglesi-Lotz, "Just Energy Transition of South Africa in a Post-COVID Era," *Sustainability*, vol. 15, no. 14, p. 10854, 2023.

[40] S. Yadav and S. Kumar, "Design and implementation of an automatic solar tracking system using PIC microcontroller," *International Journal of Electrical and Electronics Engineering*, vol. 17, no. 1, pp. 1-9, 2022.

[41] N. Frilingou *et al*., "Navigating through an energy crisis: Challenges and progress towards electricity decarbonisation, reliability, and affordability in Italy," *Energy Research & Social Science*, vol. 96, p. 102934, 2023.

[42] T. A. Taha, M. K. Hassan, N. I. A. Wahab, and H. I. Zaynal, "Red Deer Algorithm-Based Optimal Total Harmonic Distortion Minimization for Multilevel Inverters," *2023 IEEE IAS Global Conference on Renewable Energy and Hydrogen Technologies (GlobConHT)*, pp. 1-8, 2023.

[43] S. Ravichandran, M. Kumar, and M. Singh, "Design and implementation of an automatic solar tracking system using LDRs," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 8, no. 1, pp. 739-746, 2019.

[44] T. Atyia and M. Qasim, "Evaluating the Impact of Weather Conditions on the Effectiveness and Performance of PV Solar Systems and Inverters," *NTU Journal of Renewable Energy*, vol. 5, no. 1, pp. 34-46, 2023.

[45] P. B. Suresh and G. S. Kumar, "Design and implementation of an automatic solar tracking system using LDR and Arduino," *International Journal of Electrical and Electronics Engineering*, vol. 15, no. 1, pp. 1-8, 2020.

[46] A. Yadav and S. K. Singh, "Design and implementation of a solar tracking system using LDR and PIC microcontroller," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 10, no. 4, pp. 2784-2791, 2021.

[47] K. Adhikari, A. Neupane, and A. K. Poudel, "Design and implementation of an automatic solar tracking system using Arduino," *Journal of Electrical Systems and Information Technology*, vol. 11, no. 1, pp. 205-214, 2022.

[48] A. A. Elmahdy and M. A. Abdelaziz, "Performance evaluation of solar tracking systems: A review," *Renewable and Sustainable Energy Reviews*, vol. 157, p. 112180, 2022.

[49] K. Gandhi and S. Kumar, "Design and performance evaluation of a single axis solar tracking system using Arduino," *International Journal of Electrical and Electronics Engineering*, vol. 16, no. 1, pp. 1-7, 2021.

[50] A. Yadav, S. K. Singh, and R. Srivastava, "Performance evaluation of a solar tracking system using LDR and PIC microcontroller," *International Journal of Engineering and Technology*, vol. 11, no. 2, pp. 147-152, 2022.

[51] A. I. Lawah, A. A. Ibrahim, S. Q. Salih, H. S. Alhadawi, and P. S. JosephNg, "Grey Wolf Optimizer and Discrete Chaotic Map for Substitution Boxes Design and Optimization," *IEEE Access*, vol. 11, pp. 42416-42430, 2023.

[52] U. Beyaztas, S. Q. Salih, K. -W. Chau, N. Al-Ansari, and Z. M. Yaseen, "Construction of functional data analysis modeling strategy for global solar radiation prediction: application of cross-station paradigm," *Engineering Applications of Computational Fluid Mechanics*, vol. 13, no. 1, pp. 1165-1181, 2019.

[53] H. I. Zaynal, A. S. T. Hussain, T. A. Taha, A. A. Yass, S. R. Ahmed, and S. A. Ahmed, "High Pressure Water Solar Collector as Potential of Mini Steam Power Plant in Iraq," *2023 7th International Symposium on Innovative Approaches in Smart Technologies (ISAS)*, pp. 1-9, 2023.

[54] F. Chabane, A. Arif, N. Moummi, and A. Brima, "Prediction of Solar Radiation According to Aerosol Optical Depth," *Iranica Journal of Energy & Environment*, vol. 11, no. 4, pp. 271-276, 2020.

[55] M. A. Sharif, K. S. Khalaf, and M. A. Omer, "A Simulation Model of a System-based Concentrated Solar Power System (CSP) for Maximum Solar Energy Harvesting Applications," *NTU Journal of Renewable Energy*, vol. 4, no. 1, pp. 26-35, 2023.

[56] T. A. Taha, M. K. Hassan, H. I. Zaynal, and N. I. A. Wahab, "Big Data for Smart Grid: A Case Study," *Big Data Analytics Framework for Smart Grids*, pp. 142-180, 2024.

[57] M. Moghaddam, S. Ehsanzadeh, and S. M. Asadi, "Improving the performance of perovskite solar cells with carbon nanotubes as a hole transport layer," *Solar Energy*, vol. 206, pp. 807-816, 2020.

[58] D. Dastan *et al*., "Insights into the photovoltaic properties of indium sulfide as an electron transport material in perovskite solar cells," *Scientific Reports*, vol. 13, no. 1, p. 9076, 2023.

[59] A. S. T. Hussain, S. A. Ahmed, and T. A. Taha, "Early fault identification for operating circuit breaker based on classifier model system," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 26, no. 2, pp. 699-706, 2022.

[60] O. Ahmed, A. Hassan, and R. Doud, "Numerical and experimental assessment of PV/Solar Chimney," *NTU Journal of Renewable Energy*, vol. 2, no. 1, pp. 50-60, 2022.

[61] M. Amir *et al*., “Energy storage technologies: An integrated survey of developments, global economical/environmental effects, optimal scheduling model, and sustainable adaption policies,” *Journal of Energy Storage*, vol. 72, p. 108694, 2023.

[62] M. Al-Kaabi, S. Q. Salih, and V. Dumbrava, “Optimal power flow based on grey wolf optimizer: Case study Iraqi super grid high voltage 400 kV,” *Energies*, vol. 16, no. 1, p. 160, 2023.

[63] T. Hopkins, “Effectively Managing Today’s Transformer Challenges for Increased Asset Reliability & Sustainability,” in *2023 IEEE PES Grid Edge Technologies Conference & Exposition (Grid Edge)*, pp. 1-5, 2023.

[64] N. Bozsik, A. Szeberényi, and N. Bozsik, “Examination of the Hungarian Electricity Industry Structure with Special Regard to Renewables,” *Energies*, vol. 16, no. 9, p. 3826, 2023.