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Design and Mechanical Assembly of a Solar Powered Bicycle

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Abstract: The global rise in automobile usage has led to increased pollution levels due to the substantial release of carbon dioxide and other greenhouse gases into the atmosphere. This reliance on automobiles also drives significant petroleum consumption. With escalating oil prices, there is a notable shift towards alternative energy sources, with electricity emerging as a prominent option. This transition aims to combat pollution and reduce dependency on fossil fuels, facilitated by the growing availability and affordability of electric vehicles. Electric bicycles (e-bikes) are experiencing unprecedented adoption rates among alternative-fueled vehicles in motorization history, attracting the attention of researchers worldwide. Moreover, solar e-bikes represent a recent innovation in the world of electric bicycles, offering a sustainable and environmentally friendly transportation solution by capitalizing on renewable energy sources. This paper focuses on enhancing the utilization of solar energy for prolonged bicycle operation. This goal is realized by integrating a photovoltaic panel onto the bike's roof. To maximize solar energy absorption, a sun tracker is integrated, featuring light intensity detection for precise panel orientation adjustments to track sunlight. This approach tackles a key hurdle in solar energy utilization by ensuring the panels generate peak power through dynamic orientation adjustments facilitated by the sun tracker.

Keywords: Sustainable transportation, E-bike, Renewable energy source, Solar-powered bicycle, PV solar panel, LDR sensor.

1. Introduction

Transportation plays a crucial role in any country's economy and significantly contributes to its Gross Domestic Product (GDP). The continuous increase in the number of vehicles owned and the distance traveled by vehicles each year has led to a significant increase in mobility in societies where cars are dominant. Additionally, the growing number of trucks has facilitated industries in transporting goods quickly and efficiently to markets. In fact, the levels of car ownership and travel within a society are often considered indicators of the wealth and progress of a country [1].

However, the primary methods of global transportation face two major issues: the mounting costs of oil and the increasing levels of carbon emissions. In terms of energy consumption, the transportation sector has the most significant environmental impact, contributing to over a quarter of the world's energy usage and greenhouse gas emissions. Road transport alone is responsible for more than 70% of emissions in this sector [2]. This environmental impact has direct consequences on human health, as transportation also emits harmful gases such as NO_x, CO, SO_2, volatile organic compounds, and heavy metal particles like lead, cadmium, copper, chromium, nickel, selenium, and zinc. These pollutants, often combined with particles from the road, can lead to acute and chronic respiratory issues and exacerbate existing health conditions [3].

Furthermore, the transportation sector, heavily reliant on oil-based energy, faces significant challenges due to oil price fluctuations. In recent decades, there has been unprecedented volatility in oil prices, notably impacting demand within transportation. Sharp increases in oil prices have spurred policy developments and innovations in energy utilization within transportation, such as the implementation of higher fuel economy standards by manufacturers. Moreover, oil prices wield substantial influence over national economies and asset markets. The transportation sector bears a heavy burden from the expenses associated with oil-based fuels, experiencing frequent and substantial price changes. These fluctuations, commonly referred to as oil price shocks, hold considerable economic importance, particularly in shaping energy consumption within the transportation sector [4].

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Thus, to address the challenges of oil dependency and reduce emissions in the transportation sector, the concept of "sustainable transportation" has gained prominence. Sustainable transportation refers to a transport system that can meet the necessary capacity and performance standards, relies on renewable energy sources (RES), aligns with preferred lifestyles, and is both environmentally friendly and cost-effective [1, 2].

In this context, the electrification of vehicles is seen as a crucial route to achieving a worldwide transition toward sustainable transportation [5]. Electrification using RES is emerging as a significant solution for curbing carbon emissions in the transportation sector. According to a report by the International Renewable Energy Agency (IRENA), it is anticipated that renewable energy will account for around two-thirds of total energy consumption by 2050. Electricity has taken center stage as the primary energy carrier, surging from an initial 20% share in final consumption to nearly 50% [6].

Moreover, studies indicate that the combination of renewable electricity and extensive electrification in the transport sector has the potential to significantly reduce carbon emissions by roughly 60% by 2050. What makes this approach even more attractive is the rapidly decreasing costs associated with it, making it a more cost-effective option than fossil fuel-based alternatives. This transition also contributes to a reduction in local air pollution and offers various positive socio-economic benefits [6].

There are three primary types of electric vehicles (EV): hybrid electric vehicles (HEV), fuel cell electric vehicles (FCEV), and EV. According to [7], plug-in hybrid electric vehicles (PHEVs) in a municipal fleet can be categorized into six distinct groups: electric bicycles and standard bicycles, urban electric cars designed for street usage, high-speed urban electric vehicles, low-speed electric cars, high-performance electric supercars, and electric buses and electric trucks [8].

Electric bicycles (e-bikes), experiencing the largest and swiftest adoption among alternative-fueled vehicles in the history of motorization, have captured the interest of researchers worldwide, who are exploring various aspects of their ownership and usage [9]. Rapidly gaining popularity as a mode of transportation in various parts of the world, such as China and Western Europe, e-bikes saw over 40 million units sold globally in 2015 alone, with projections indicating continued growth. It's anticipated that sales could reach 130 million by 2025 and a staggering 800 million by 2100. E-bikes offer a faster alternative to traditional bicycles, potentially enhancing their role in urban transportation systems, with typical operating speeds ranging from around 21.86 km/h to over 30 km/h, notably faster than regular bicycles. Recent studies have shown average speed differences of 2–9 km/h between e-bikes and traditional bikes [10].

An e-bike is a traditional pedal bicycle equipped with an electric motor and a rechargeable battery to aid in propulsion. The addition of power assistance helps overcome various obstacles to cycling, such as advancing age, physical constraints, challenging terrain, time constraints, and the perceived level of fitness required to cycle. While power assistance facilitates easier riding, cyclists still derive some physical activity benefits from pedaling. Compared to a conventional bicycle, riding an e-bike requires less physical effort, making e-bikes appealing to individuals with physical limitations or as a rehabilitative tool. E-bikes also offer additional assistance for transporting items or children [9].

Solar e-bikes represent a recent innovation in the realm of electric bicycles, featuring built-in photovoltaic (PV) solar cells on various parts of the bike's frame [11]. PV panels harness sunlight to generate electricity directly. These panels are composed of multiple interconnected cells that generate electricity at a specified voltage. Essentially DC devices, PV panels require an inverter to convert the electricity into AC. Typically crafted from crystalline silicon, PV cells generate current relative to the intensity of solar radiation, up to a specific voltage limit. Since power is proportional to the product of current and voltage, the power from a PV cell will continue to increase until the current begins to drop [12].

This design of the solar e-bikes allows it to harness solar energy, charging their batteries not only during rides but also when stationary. Another variation, the solar-charged e-bike, relies on a charging system powered by PV solar modules. These bikes can be conveniently connected to solar-powered charging stations for battery replenishment while parked [11].

A. Motivation and Problem Statement

Bicycling has experienced a resurgence as a preferred mode of urban transportation, particularly for short distances. This trend benefits both individuals and cities alike. For riders, biking provides a swift and healthy means of getting around, while for cities, it offers a pathway to environmental sustainability by reducing reliance on cars, particularly for brief trips, thereby easing traffic congestion [13].

Simultaneously, there's a growing recognition of the sun's significance as a renewable energy source, with considerable potential for various applications aimed at diminishing dependence on finite, polluting traditional fuels [14].

In regions like the GCC countries, where solar potential is high and solar energy exposure is abundant, the development of solar-powered bicycles holds particular significance due to their unique environmental characteristics and geographical location [15]. Past projects in these areas have demonstrated promising outcomes, underscoring the favorable conditions for further investment in renewable energy sources like solar power.

Solar photovoltaic (PV) technology brings with it a host of advantages, including minimal maintenance, reduced emissions, and cost savings driven by technological advancements and increased solar array production [16]. These benefits can be harnessed in the creation of solar-powered bicycles.

Moreover, the integration of sun-tracking systems atop solar-powered bicycles presents a revolutionary solution for enhancing energy conversion efficiency [17]. By automatically adjusting the orientation of PV panels to align with the incident sunlight throughout the day and across seasons, these bicycles overcome challenges faced by traditional PV panels in maintaining optimal positioning. This dynamic adjustment ensures maximum exposure to sunlight at all times, significantly boosting energy collection efficiency, even in diverse topographic conditions, with potential improvements ranging from 10% to 100%.

Thus, the conjunction of bicycling's resurgence as urban transportation and the emergence of solar energy technology offers a compelling narrative for exploring the development of solar-powered bicycles as a sustainable mobility solution.

B. Literature Review

In reviewing the existing literature surrounding the domain of solar-powered bicycles, it becomes evident that various studies have explored innovative solutions to enhance the efficiency and sustainability of traditional bicycles. Noteworthy contributions include investigations into pedal-only bicycles, motorized bicycles fueled by conventional sources, and limited-range electric bicycles. The literature reveals a growing interest in addressing the limitations of these conventional models through the integration of solar energy.

For example, the study presented in [18] discusses the concept of a solar bicycle as a solution to enhance the efficiency and sustainability of conventional bicycles. In contrast to pedal-only and limited-range electric bicycles, the solar bicycle integrates a high-torque motor powered by renewable solar energy. The portable solar panel charges the bicycle's battery when not in use, ensuring continuous power availability. The system allows the motor to use solar-generated power directly, and when necessary, it can draw power from the battery. The integration of a controller manages the power flow from the battery to the electric motor, providing flexibility for riders to use the motor exclusively, pedal alongside motor assistance, or pedal independently. This innovative approach aims to make bicycles perpetually efficient and environmentally friendly by harnessing solar energy for enhanced mobility.

Moreover, the paper in [19] discusses the design of an electric-driven bicycle incorporating solar energy to generate power. The design includes a rear-wheel motor, and the vehicle is intended for a single driver, with no provision for additional passengers or materials. The motivation for this design is the high pollution rate in India caused by fuel-consuming vehicles. Given the extended sunny weather in India, lasting approximately 9 months, the paper suggests that solar-powered bicycles could serve as a viable alternative to traditional fuel-powered bikes and scooters, aiming to reduce fuel consumption and associated hazardous emissions.

Furthermore, in [20], the development of hybrid solar-powered bicycles is discussed. The developed bicycle combines renewable solar energy and the rider's pedaling energy for propulsion. The bicycle serves as a low-cost alternative, with an average speed ranging from 12 to 15 km/h. In the absence of solar energy, the rider's pedaling serves as a backup energy source. The paper proposes a comprehensive redesign of traditional bicycles into hybrids, providing clear experimental investigations. It reviews existing reports on hybrid bicycles and suggests an implementation method for easier modification. The redesigned hybrid bicycle is compared with two-stroke engine-based vehicles.

Additionally, the study in [21] introduces the concept of a solar bicycle as a means to control vehicle emissions. The proposed solar bicycle aims to utilize energy loss through a flywheel during sudden braking, automatically recharging it with renewable solar energy. Additionally, the bicycle can be driven using the traditional pedaling method.

Also, the paper in [22] outlines a hybrid bicycle system project that integrates three charging methods for a lithium-ion battery: a 220VAC wall outlet, regenerative braking, and solar power. The system powers an electric hub motor attached to the bicycle's front wheel. The compact and lightweight hub motor features a regenerative charge system and solar panels. This configuration allows for extended distance power-assisted cycling by harnessing energy from pedaling and solar sources, subsequently charging the battery.

Likewise, the study presented in [23] discusses a solar-powered e-cycle project that aims to provide an alternative transportation solution by utilizing solar energy to charge the battery, which then powers the motor. Solar panels are mounted on the bicycle, and the battery is connected to a solar charge controller, converting solar energy into electrical power. This stored energy is supplied to a DC gear motor that drives the bicycle. The transformation from a conventional product to a less polluting and compact mobility tool signifies a shift in transportation. The study focuses on designing an affordable solar e-cycle with enhanced solar energy utilization, anticipating a preference for electric vehicles over fuel-powered ones in the future.

Additionally, in [24], the creation, implementation, and performance assessment of a solar-driven electric vehicle is presented. This vehicle relies on energy generated by PV modules and stored in a battery. It's equipped with a monitoring system to oversee the voltage and current levels of the PV modules. Several tests were conducted to gauge the vehicle's performance, confirming its ability to operate for prolonged periods.

Furthermore, the study presented in [25] introduces a solar bicycle designed for use in India. With abundant sunshine spanning nine months of the year, India provides an ideal environment for solar-powered transportation. The bicycle featured in the study adopts a hybrid design, combining solar energy with a pedal-powered dynamo to charge the battery and propel the bicycle.

Moreover, in [26], a novel solar electric bicycle is introduced, utilizing a hardware setup featuring a permanent magnet direct current motor. The prototype presented in the paper undergoes experimental validation in real-world scenarios to verify its performance.

Also, in [27], a technique is described for transforming a conventional bicycle into an electric-powered bicycle, utilizing a hub motor powered by a battery. Moreover, the method involves converting an electric-powered bicycle into a solar-powered electric bicycle by integrating solar panels onto the bicycle frame. These solar panels are installed on the bicycle, and the hub motor is linked to facilitate smooth riding. A solar controller is integrated with the battery to convert solar energy into electrical energy. A battery is employed to store the electrical power and provide the necessary supply to the hub motor for motor operation.

In addition, in [28], an electric bicycle equipped with a 100 Wp solar panel is examined to evaluate its charging efficiency. Solar radiation absorbed by the photovoltaic (PV) module was measured using a solar power meter, while sensors recorded the DC output current and voltage from the solar panels. These sensor signals were processed by a microcontroller and displayed on an LCD screen, with data also logged onto an SD card. Comparisons were made between the charging voltage characteristics with and without the PV module. Findings revealed that at a solar radiation level of 1008 W/m², the maximum voltage and current recorded were 17.49 V and 3.37 A, respectively. Under these conditions, the battery charging efficiency of the 100 Wp solar panel was calculated at 58.94%. Additionally, a one-hour test conducted under an average solar radiation of 976.3 W/m² demonstrated a 33.33% increase in energy storage in the e-bike battery with the integration of the 100 Wp PV module. These results suggest that the hybrid solar e-bike concept holds promise for enhancing the performance of electric vehicles in the future.

Furthermore, the study outlined in [29] focuses on the utilization of solar panels for charging batteries on electric bicycles. The research entails various stages, including bicycle preparation, design development, fabrication of the solar panel frame and holder, and assembly and testing procedures. The outcome of the investigation is an electric bicycle equipped with a 24V, 12Ah battery, requiring 9 hours and 33 minutes for charging, powered by a 250-Watt DC motor. The electric bicycle's maximum speed reaches the anticipated 20 km/hour, covering a distance of 16 km with a load of 89 kg. However, the mileage and travel duration are subject to variations based on the rider's weight.

Moreover, the study in [30] introduces a hybrid e-bike system, comprising a bicycle equipped with an electric hub motor for propulsion assistance, alongside a solar package featuring essential components. This research involves evaluating the distance traveled over time under two conditions: solely using batteries and utilizing batteries in conjunction with photovoltaic (PV) modules, tested at various times throughout the day. A comparative analysis between the two methods is conducted and documented in this paper. The objective is to provide insights into the performance and user experiences associated with e-bike usage. The average commuting distance per hour is approximately 6.8 km/h. It is imperative to ensure that the current limitations do not exceed 10.4A, while avoiding shading on the solar panels caused by the rider. Furthermore, depending on the solar irradiance over time, the hybrid e-bike demonstrates a longer traveled distance compared to the battery-only scenario.

In contrary to the previous studies, in this paper, the primary focus is on maximizing the utilization of solar energy to ensure prolonged operation of the bicycle. This is achieved by integrating a photovoltaic panel onto the top roof of the bike. To optimize solar energy capture, a sun tracker is incorporated and equipped with light intensity detection capabilities, enabling efficient panel orientation adjustments to follow the sunlight. This innovative approach addresses one of the main challenges in solar energy utilization— ensuring the solar panels generate maximum power through the sun tracker technology, which dynamically adjusts panel orientation for enhanced efficiency.

2. DESIGN APPROACH

In this section, an exploration of the foundational elements of the solar-powered bicycle project will be presented. This includes an in-depth examination of the system architecture, revealing the details of the hardware components. Subsequently, the details of the system design will be unfolded, providing a comprehensive understanding of its structure and functionality. Additionally, the calculations performed for this project will be discussed.

A. System Architechture

This section provides an in-depth exploration of the solar-powered bicycle's system architecture. It thoroughly examines the essential hardware components, shedding light on their functionalities and interconnections. Refer to Fig. 1 for a visual representation of the system architecture.

1) Arduino UNO R3 SMD: The Arduino UNO R3 SMD is a microcontroller board based on the ATmega328. Equipped with 14 digital input/output pins (with 6 capable of functioning as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button, the Arduino operates by either connecting it to power or linking it to a computer via USB.

2) LDR sensor: The light dependent resistor (LDR) sensor is a light-sensitive photoresistor module used to detect light in specific areas. This module is versatile and finds applications in cameras, solar garden lights, and other automatic lighting systems. The LDR sensor is known for its sensitivity, fast response, high stability, and reliability, even in conditions of elevated temperature and humidity, providing an analog output. The LDR sensor was chosen for this project due to its small size, allowing flexible mounting on the bike in areas exposed to light.

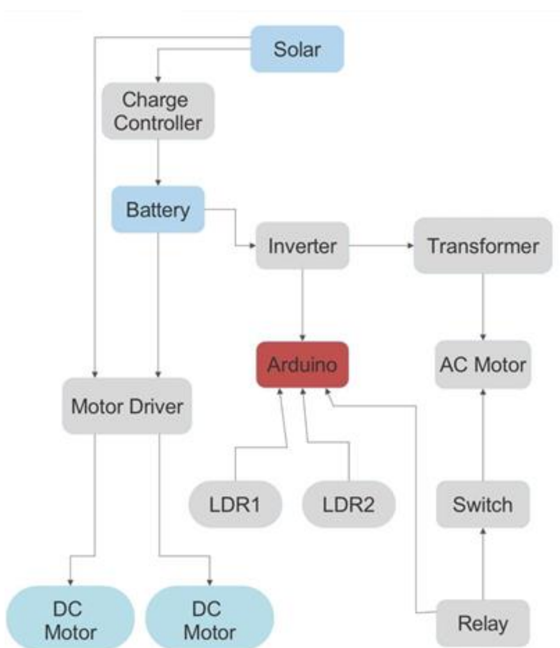

Figure 1. System architecture of the proposed solar powered bicycle

3) Breadboards: Breadboards are essential tools for constructing electrical circuits without soldering. They are particularly useful for small components and units. Whether dealing with complex or simple circuits, a solderless breadboard is an ideal starting point for any electronic system.

4) PV solar panel: The solar panel plays a crucial role in the project by utilizing photovoltaic technology to convert light energy into electricity. Its primary functions include power generation, effectively managing energy consumption, and serving as a power source for various project components. The cells in the panel are equipped to detect light or electromagnetic radiation within a specific range, measure light intensity, and efficiently harness sunlight absorption for electrical power generation.

5) DC motor: The selected DC motor, drawing 1.8 A and rotating at 15 rpm, was chosen for this project due to its simplicity in handling the specific task of orienting the solar panel towards the sun, necessitating straightforward left and right movement. To regulate motor speed, an Arduino analog output (PWM) is utilized, allowing control with a numerical range of 0 to 255 through the serial monitor.

6) AC motor: In this project, a 110V AC motor was employed to propel and maneuver the motorbike. This particular AC motor, featuring a torque of 64 rpm and an 80W power consumption, was chosen for its ability to generate substantial torque, essential for moving the bike with the anticipated rider's weight.

7) Inverter: An inverter serves the purpose of converting DC to AC, allowing the conversion of power from the 12V battery to 220V AC. The employed inverter is rated at 500W to facilitate voltage inversion.

8) Solar charge controller: A solar charge controller is responsible for regulating current and voltage to prevent batteries from overcharging by managing the incoming current and voltages from the solar panel. Voltage regulation is essential because solar panels often generate a higher voltage than their rated value; for instance, a 12V panel may produce 16-20V, posing a risk of damage to the battery and other components.

9) Step-down transformer: A step-down transformer is a device designed to decrease voltage levels from a higher voltage to a lower one, utilizing both primary and secondary windings. In this project, this transformer plays a crucial role in reducing the inverted voltage from the battery (converted to 220V AC) to 110V. This adjusted voltage is then employed to activate the motor, powering the movement of the motorbike.

10) Limit switch: The limit switch functions as a circuit controller, enabling the circuit to be turned on or off, essentially interrupting the voltage flow. In this project, a limit switch was incorporated to disrupt the circuit when the brakes are fully engaged. This action sends a signal to the relay, preventing the AC motor from turning and thereby safeguarding it from potential damage.

11) Relay: Connected to the limit switch, the relay receives signals from the limit switch, interrupting the circuit when the motorbike comes to a halt. This circuit interruption, initiated by fully pressing the brake and bringing the motorbike to a standstill, prevents potential damage to the AC motor. Releasing the brake reinstates the circuit, allowing the motorbike to operate normally. In essence, the relay functions as an automatic switch.

12) Motor driver: The motor driver establishes a connection between the DC motor and the LDR sensors, enabling the movement of the solar panel in the direction of the sun. LDR sensors determine the sun's direction, transmitting signals to the motor driver, which, in turn, commands the DC motor to adjust the panel towards the sun. To address the power requirements of the solar panel's DC motor (4A), a robust 10A motor driver was selected, ensuring efficient operation without the risk of overheating.

13) Battery: A rechargeable 12V battery powers the motorbike in this project, providing ample capacity for the circuit's needs. This battery was selected due to its compatibility with solar panel charging and its suitable size for installation beneath the seat, where space was constrained.

B. System Design

The system execution begins with the initialization of microcontroller ports for handling system inputs and outputs. Initially, the LDR sensor captures light intensity as an analog input, converting it into digital signals sent to the microcontroller, which processes instructions for the proper action. The main circuit, assembled on a breadboard for flexibility as shown in Fig. 2, connects all components into a unified circuit to exchange signals and instructions. Its primary function is to receive power from the solar panel, store it in a 12V lithium battery, and use it to operate the DC motor as shown in Fig. 3. Additionally, the main circuit signals the switch controlling movement and adjusts the solar panel's direction.

The LDR, functioning as a sensor with variable resistance, responds to changes in light intensity from the sun. The circuit receives voltage alterations based on light intensity and resistance, where higher sun intensity results in less resistance, sending a higher current to the microcontroller, indicating high light intensity.

The main circuit is designed to encompass the entire system and power the bike. It includes the solar charger circuit (Fig. 4), responsible for receiving and storing solar energy in the battery to power the system, the sun tracker circuit, adjusting the solar panel based on sun movement, and the LDR sensor efficiently capturing sunlight. Bike movement is controlled using a relay, which opens or closes the current pathway through the switch.

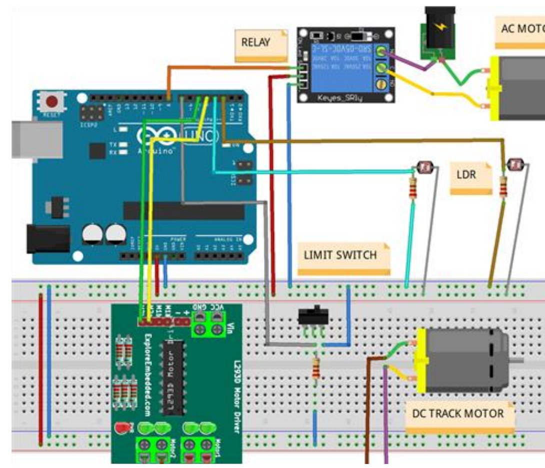

Figure 2. Main circuit connections

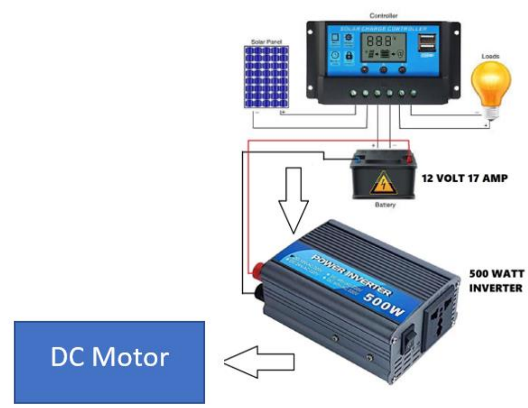

Figure 3. Solar charge controller

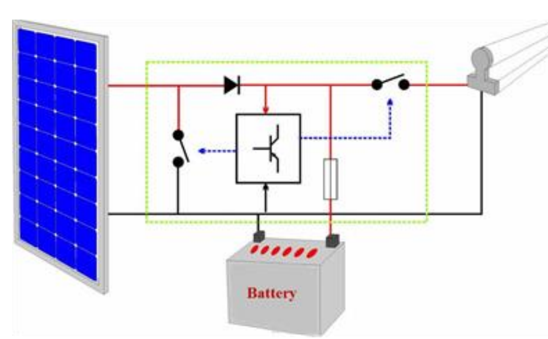

Figure 4. Solar charge connection

C. Calculations

This section explores the mathematical formulations used for the design and functionality of the project.

1) Energy consumption: The components selected for this project had a cumulative power output of 150W to achieve continuous one-hour operation for the bicycle. This duration was specifically chosen as it is deemed ample for transportation between locations in Kuwait. The calculation made was based on (1).

$$E = P \times t \quad (1)$$

Where E is the energy consumption, P represents the power, and t is the time in hours.

2) Peak power of PV: Eq. (2) represents the formula used to calculate the peak power obtained from the PV solar panel, and (3) shows the values used in the calculation.

$$P_{pv} = \frac{E}{N_{inv} \times N_{con} \times PSH} \times SF \quad (2)$$

$$P_{pv} = \frac{150}{0.9 \times 0.92 \times 5.5} \times 1.15 = 37.8\ W \quad (3)$$

Here N_{inv} is the invertor's efficiency, N_{con} is the controller's Efficiency, PSH represents the peak sun hours in Kuwait, and SF is the safety factor = 1.15.

3) Number of Batteries required: It was essential to determine the required number of batteries to provide sufficient power for the motorbike's operation. Therefore, given that the selected battery is a 12V with an 18A capacity, a single battery proved to be sufficient according to (4) and (5).

$$P = V \times I \quad (4)$$

$$P = 12 \times 18 = 216\ W \quad (5)$$

Here P represents the power, V the voltage, and I the current.

4) Number of panels required: Given that the chosen panel for this project had a power capacity of 100W and that an energy consumption rate of 150 W.h was required, a single panel was sufficient to charge the motorbike's battery according to (6), and (7).

$$\text{Number of panels} = \frac{E}{PSH \times P} \quad (6)$$

$$\text{Number of panels} = \frac{150}{5.5 \times 100} = 0.3 \quad (7)$$

Here E is the energy consumption, PSH represents the peak sun hours, and P the power.

3. IMPLEMENTATION

Implementing the design of the solar-powered bicycle involved three phases: mechanical, electrical, and software implementation. Thus, this section will explore the intricacies of these implementation phases.

A. Mechanical Assembly

After acquiring an appropriately sized bicycle, the steel framework was utilized to fabricate supports for securing solar panels and the corresponding brackets essential for sun tracking functionality. The mounts, welded onto the bicycle, accommodated various components, including four metal pipes for solar panel attachment, a movable base, visible in Fig. 5, and two footrests for the driver. A designated space beneath the seats was established for installing electrical components, featuring a sliding closure to secure circuits and wires. Additionally, Styrofoam was welded beneath the seat to support smaller electrical elements.

Subsequently, the AC motor was affixed to the chassis near the bicycle chain as depicted in Fig. 6. This enabled the connection of a secondary chain to the sprocket, allowing the primary chain to propel the bicycle through the rotation of the secondary chain, linked to the AC motor. Additionally, a DC motor, welded in place, moved a shaft responsible for controlling the solar tracking panel. The movement was controlled by signals transmitted from the LDR sensor to the Arduino microcontroller, issuing commands to the motor driver.

Figure 5. The solar-powered bicycle.

Figure 6. The solar-powered bicycle with the AC motor mounted on it.

B. Electrical Implementation

The solar panel works by connecting wires from the panel to both the solar charge controller and the motor driver. This configuration allows the motor drive to regulate the solar panel's movement, while the charge controller connects it to the battery for charging. The stored battery power is directed to an inverter (Fig. 7), which converts the voltage from DC to AC. This AC power then passes through a transformer (linked to the motor) to step down the voltage for the AC motor's operation.

To initiate the bike, two switches were installed, as illustrated in Fig. 8. The yellow switch activates the battery to supply power to all components. Specifically designed for continuous solar tracking even when the bike is stationary, this switch ensures that the tracker operates to detect additional light and charge the battery. While tracking consumes some power, the solar panels compensate for this loss. The second switch serves as the bike's ignition. Turning it on starts the bike's movement, gradually increasing speed. Additionally, a limit switch, placed near the brake, interrupts the circuit when the brake is applied, causing a gradual reduction in speed.

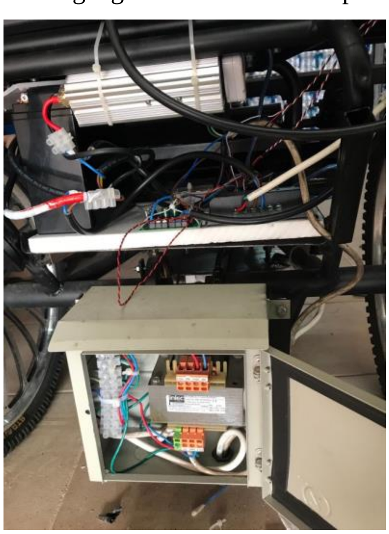

Figure 7. Transformer and inverter installed in the solar-powered bicycle.

Figure 8. Switches installed in the solar-powered bicycle.

C. Software Implementation

Implementing a sun tracker in the project involves coding to enable the controller to orient the solar panel toward the sun. The Arduino UNO, serving as the central controller, manages the solar panel movement via the motor driver using the custom-designed code. Additionally, the Arduino regulates the relay and switch, exerting control over the bike's movement.

To enhance battery efficiency, the code utilizes high or low signals to determine whether to turn the solar panel left or right. This approach eliminates the necessity for continuous comparisons and readings between different directions. Fig. 9 represents the flow chart of the operation of the Arduino UNO.

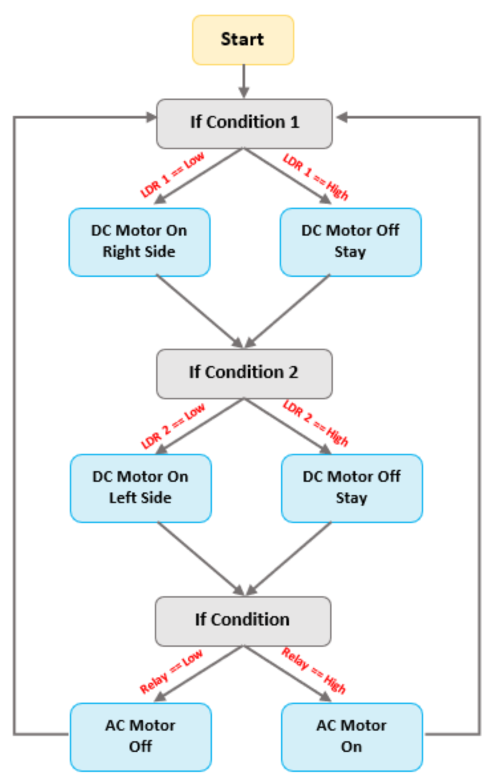

Figure 9. Flow chart of the operation of the Arduino Uno.

4. CONCLUSION

In conclusion, the solar-powered bicycle system presented in this paper marks a significant step toward sustainable and eco-friendly transportation. The integration of a photovoltaic panel with a sun tracker exemplifies a novel approach to maximizing solar energy utilization, addressing challenges associated with fuel dependence and environmental pollution. To propel this technology further, future endeavors should explore advanced solar technologies, considering flexible and lightweight solar cells for improved efficiency and aesthetic integration. Additionally, research could delve into emerging energy storage solutions, such as high-capacity batteries or supercapacitors, to extend the bicycle's range and enhance usability.

Further innovation lies in the realm of smart energy management, employing machine learning algorithms for predictive optimization. Enhanced sun-tracking mechanisms with real-time data processing and feedback loops can elevate energy harvesting efficiency. The integration of IoT features offers the potential for remote monitoring and contributes to the development of smart transportation ecosystems. Regenerative braking systems and a user-friendly interface, complete with mobile app integration, could significantly enhance the overall user experience.

Looking beyond the individual bicycle, exploring the integration of solar-powered bicycle charging stations into urban infrastructure fosters a more sustainable and widespread adoption of this technology. Collaborative research initiatives with experts from various fields, including environmental science and engineering, can yield comprehensive insights into the societal and environmental impacts of solar-powered transportation. This multifaceted approach ensures the continuous evolution of solar-powered bicycles, making them not only efficient and practical but also integral to the broader goals of sustainable mobility.

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