Design & Fabrication Single Axis Solar Tracker with DC Plus AC Invertor

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ABSTRACT

This project focuses on the development of a single-axis solar tracking system aimed at optimizing solar energy capture. Utilizing an Arduino Uno as the central controller, equipped with Atmel microcontroller technology, the system employs two Light Dependent Resistors (LDRs) to detect the sun's position in the sky. A servo motor is utilized to adjust the orientation of the Solar PV panel accordingly. Through proper interfacing, the sensors and servo motor are seamlessly integrated with the Arduino board. Mechanically, the servo motor is linked to the PV panel to enable movement. Programming for the system is accomplished using the Arduino IDE. Following assembly, thorough testing has been conducted to evaluate performance. The solar tracker adeptly adjusts the solar panel's direction to align with the sun, enhancing efficiency on a daily basis.

Renewable Energy Sources encompass energy outlets that remain intact even after their energy is harvested. Utilizing these sources necessitates technologies that tap into natural occurrences like sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production, and geothermal heat. Notably, significant advancements have been made in wind energy harnessing technology.

Keywords: Solar Energy, Automatic Tracking, Renewable Energy

I. INTRODUCTION

This project aims to optimize solar energy utilization through solar panels by implementing a digital automatic sun tracking system. By automatically adjusting the position of the solar panels to maximize sunlight exposure, the efficiency of the system is significantly increased.

To ensure maximum light intensity and minimize voltage difference (error degree), it's crucial that the solar panel remains perpendicular to the light source. However, throughout the year, a fixed Single Axis setup fails to maintain consistent output power. As the sun's position changes relative to the installed solar tracker, the panel may no longer be perpendicular to the sun, impacting power output. Therefore, a single-axis solar tracking mechanism continually adjusts the panel to remain perpendicular to the sun's rays, optimizing power generation.

Controlled by an Arduino microcontroller, the tracker's motors adjust the solar panel's alignment based on sunlight intensity. Since Arduino operates at lower voltage levels than DC motors, interfacing a DC motor with the microcontroller typically involves using an H-bridge. Many IC manufacturers offer H-bridge motor drivers like L298n, facilitating this interface.

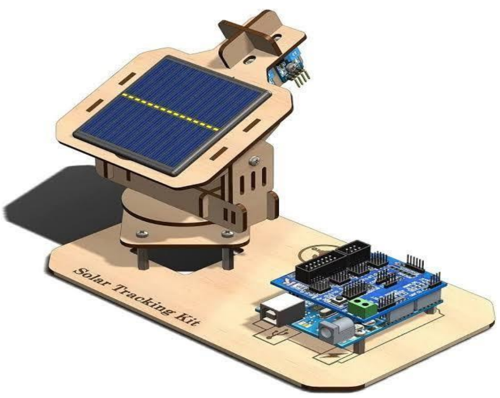
Light Dependent Resistors (LDRs) are utilized to sense light intensity, with four LDRs strategically positioned to ensure the solar panel is perpendicular to light from all directions. Maintaining uniform LDR values ensures correct panel orientation.

DC geared motors convert DC electricity into mechanical energy, driving the solar panel's movement. Gear motors offer high torque, ideal for solar tracking applications.

For those utilizing solar panels, whether on camper vans for camping trips or at home to supplement or replace grid electricity, aligning panels directly towards the sun is crucial for optimal performance. Solar trackers, employing various mechanisms, ensure panels track the sun's movement throughout the day, maximizing energy capture.

There are two primary types of solar trackers: single axis and dual axis. Single axis trackers are adjusted approximately every month to accommodate seasonal changes in the sun's position. They utilize a single axis to track the sun's daily movement across the sky. On the other hand, dual axis trackers eliminate the need for monthly adjustments by employing one axis to track the sun's daily movement and another axis to track its seasonal movement. According to an article on Attestor, a single axis solar tracker can enhance solar output by around 25%, while a dual axis tracker can boost it by approximately 40%.

The control system for this solar tracker is designed to measure light from both the east and west sides (left and right) of the solar panel. Based on these measurements, it determines the direction in which to move the panel to align it directly with the light source. A servo mechanism is employed to adjust the panel's orientation, with servos available in a wide range of sizes that can be scaled to suit the panel size. Although this tracker is single axis, it's possible to achieve dual axis control by duplicating the sensors and servo mechanisms.



This project assumes a basic understanding of Arduino programming. If you're new to Arduino, I recommend reading my article on getting started with Arduino before diving into this project.

Furthermore, you can expand on this project by constructing your own solar panel. Check out our guide on how to build a solar panel at home for detailed instructions.

If you're considering transitioning some or all of your home's power needs to solar energy, I suggest reading my article on switching to solar power first for valuable insights and considerations.

II. LITERATURE REVIEW

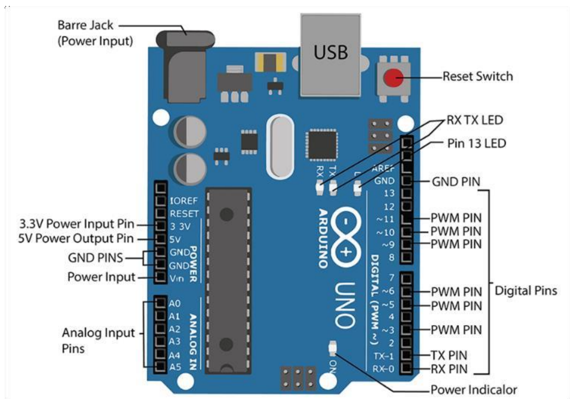
Photovoltaic is defined that using sun light to generate the electricity. Sunshine hits photovoltaic cells or a mirror arrangement and electricity is generated. In the second half of 20th Century, the development of photovoltaic cells technology was moving rapidly, although Edmond Becquerel has observed the effect of photovoltaic in 1839. A Cambridge scientists Adams was published his first research report of photovoltaic report in 1877. Next, selenium solar cell was built by Charles Fritts in 1883, even though the efficiency less than 1% but it is similar to contemporary silicon solar cells. First modern silicon solar cells were manufactured in 1954 by Chapin, Fuller and Person, the solar element with p-n junction was achieved 6% efficiency of system. The cost of initial commercial manufactures was high and relatively low efficiency in 5 – 10%. In addition, the solar cells were mainly made by crystalline material such as crystal silicon (c-Si). The sun is the largest energy source of life at the same time, it is the ultimate source of all energy (except power of geothermal). The sun radiates 174 trillion kWh of energy to the earth per hour. In other words, the earth receives 1.74 x 10 17 watts of power from the sun

Characteristics of the sun is simplified as follows: mass 2× kg, beam length 700.000 km, age 5× years and estimated roughly 5 billion more years of life. The surface temperature of sun is approximately 5800 K while the internal temperature is approximately 15.000.000 K. High temperature reactions is due to the transformation of hydrogen in helium. The process of the nuclear fusion, which is characterized from the following reaction 2H → He + Energy, is the result of the sun high temperature and the large amounts of energy emitted continuously. It is calculated that for each gram of hydrogen, that is converted to He, sun radiates energy equal with U= 1.67× kWh. The solar energy is emitted to the universe mainly by electromagnetic radiation.

The estimated distance from the sun is 150,000,000 km while the sun is stationed and spins around by the earth in an elliptic orbit. The light having the travelling speed of 300,000 km/sec to overcome the aforesaid distance, it consumed approximately 8.5 minutes. Actinic of emitted radiation is removed by the aster to the space and the intensity of radiation.

Arduino microcontrollers are pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory. The default bootloader of the Arduino UNO is the optiboot bootloader Boards are loaded with program code via a serial connection to another computer.

Some serial Arduino boards contain a level shifter circuit to convert between RS-232 logic levels and transistor- transistor logic (TTL) level signals. Current Arduino



boards are programmed via Universal Serial Bus (USB), implemented using USB-to-serial adapter chips such as the FTDI FT232. Some boards, such as later-model Uno boards, substitute the FTDI chip with a separate AVR

chip containing USB-to-serial firmware, which is reprogrammable via its own ICSP header.

Other variants, such as the Arduino Mini and the unofficial Boarduino, use a detachable USB-to-serial adapter board or cable, Bluetooth, or other methods. When used with traditional microcontroller tools, instead of the Arduino IDE, standard AVR in-system programming (ISP) programming is used.

III. Developing the System

Two critical components in this system are the CD4047 multivibrator and the IRF540 MOSFET transistor.

The CD4047 multivibrator, manufactured by Texas Instruments, is renowned for its low power consumption. This component is designed to function as both a monostable and astable multivibrator, offering versatility in operation. Additionally, it can operate in gatable or free-running mode, providing stable frequency output. With the capability to generate a 50% duty cycle, it effectively produces the necessary pulses for the system.

The IRF540 MOSFET transistor is selected for its high switching capacity and wide current range, suitable for creating inverters ranging from 100 watts to 500 watts.

In the circuit, the 12V battery powers the LED diode and is connected to Pin 8 (VCC) of the CD4047 IC. Pins 4 and 5 of the IC serve as astable and complement pins, respectively. The LED acts as a battery indicator, confirming the system's operation.

To activate the multivibrator mode, a capacitor isconnected between Pin 1 and Pin 3, while Pin 2 is linked to a variable resistor and another resistor to adjust the output frequency. Pins 10 and 11 are connected to the gate of the IRF540 MOSFET transistor, generating a 50% duty cycle for effective operation.

To prevent MOSFET loading, resistors are connected between the output frequency and the MOSFET. The AC current generated by the MOSFETs acts as electronic switches, enabling power flow through the transformer's primary coil.

The AC power is then supplied to the step-up transformer's secondary coil to obtain higher AC voltage. A Zener diode is incorporated to bypass reverse current.

To scale the circuit for inverters ranging from 100 wattsto 500 watts, ensure the transformer's wattage rating exceeds the required output and the Ampere-hour (AH) rating is ten times greater than the transformer's primary amp rating.

Working of the solar powered system

Solar energy stands as a prominent renewable resource with diverse applications, spanning power generation, water heating, calculators, chargers, lamps, and more. Its integration into electric power generation presents notable advantages, including minimal pollution, cost-effectiveness (disregarding installation costs), and hassle-free operation. A typical solar power setup consists of solar panels, solar photovoltaic cells, and batteries for energy storage. The direct current (DC) power generated by solar panels can either be stored in batteries, supplied to DC loads, or converted by an inverter to power alternating current (AC) loads.

Solar panels, constructed from solar photovoltaic cells, effectively convert solar energy into electrical energy. These panels utilize Ohmic materials for interconnections and external terminals. Electrons generated within the N-type material are channeled towards the battery through electrodes and wiring. Subsequently, these electrons migrate to the P-type material, where they unite with holes. As a result, when linked to the battery, the solar panel behaves akin to an additional battery, resembling the configuration of two batteries connected in series.

Arduino IDE

The ATMega328p microcontroller IC with Arduino bootloader makes a lot of work easier in this project as Arduino code is written in C++ with an addition of special methods and functions, which we'll mention later on. C++ is a human-readable programming language. When you create a 'sketch' (the name given to Arduino code files), it is processed and compiled to machine language.

The Arduino Integrated Development Environment (IDE) is the main text editing program used for Arduino programming. It is where you'll be typing up your code before uploading it to the board you want to program. Arduino code is referred to as sketches.

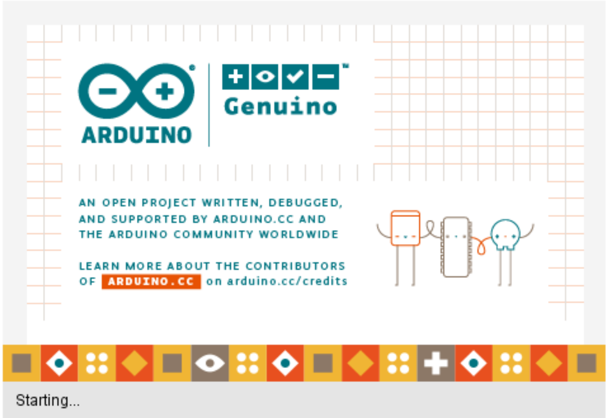


Fig. 3.1 Arduino IDE

ARDUINO UNO: -

The Arduino Uno is a microcontroller board based on the ATmega328.It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Arduino board designs use a variety of microprocessors and controllers.

The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards or breadboards (shields) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers.

The microcontrollers are typically programmed using a dialect of features from the programming languages C and C++. In addition to using traditional compiler toolchains the Arduino project provides an integrated development environment (IDE) based on the Processing language project.

Most Arduino boards consist of an Atmel 8-bit AVR microcontroller (Atmega8,[24] Atmega168, Atmega328, Atmega1280, Atmega2560) with varying amounts of flash memory, pins, and features.[25] The 32-bit Arduino Due, based on the Atmel SAM3X8E was introduced in 2012.[26] The boards use single or double-row pins or female headers that facilitate connections for programming and incorporation into other circuits. These may connect with add-on modules termed shields.

Multiple and possibly stacked shields may be individually addressable via an I²C serial bus. Most boards include a 5V linear regulator and a 16 MHz crystal oscillator or ceramic resonator. Some designs, such as the LilyPad, run at 8 MHz and dispense with the onboard voltage regulator due to specific form-factor restrictions.

Arduino microcontrollers are pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory. The default bootloader of the Arduino UNO is the optiboot bootloader Boards are loaded with program code via a serial connection to another computer.

Some serial Arduino boards contain a level shifter circuit to convert between RS-232 logic levels and transistor-transistor logic (TTL) level signals. Current Arduino boards are programmed via Universal Serial Bus (USB), implemented using USB-to-serial adapter chips such as the FTDI FT232. Some boards, such as later-model Uno boards, substitute the FTDI chip with a separate AVR chip containing USB-to-serial firmware, which is reprogrammable via its own ICSP header.

Developing the System

Of all the components that you need to build the system, the role of two components – CD4047 multi-vibrator and IRF540 MOSFET transistor deserve special mention.

The CD4047 multi-vibrator manufactured by Texas Instrument consumes very low power. The system is designed on a way to work both as monostable and astable multi-vibrator. Furthermore, it also operates on gatable or free running mode and provides pretty descent stability in frequency. CD4047 has the power to generate duty cycle of 50%, which actually creates the pulse.

The IRF540 MOSFET transistor is used in this development is because of its capacity for high switching and a current range which can e used for making any inverter from 100 watt to 500 watt.

Referring to Figure, the 12V battery is connected to the LED diode. The battery is also connected to Pin 8 of IC4047 i.e., the power-supply pin or VCC, and is also further connected to Pin 4 and Pin 5 which works as astable and complement of IC4047.

It is important to note here that the diode will not be able to produce any reverse current. The LED in the circuit acts as a battery indicator to see if its working. The CD4047 IC, in this development will function as astable multivibrator mode.

To make the multivibrator mode work you need to get one capacitor, which need connection between Pin 1 and Pin 3. The Pin 2 is further connected to a variable resistor and a resistor in order to update the output frequency of the IC. The rest of the pins should remain in grounded mode. Pin 10 and Pin 11 are connected to IRF540 mosfet gate. Both these pins also referred as Q and ~Q generates duty cycle of 50%.

In order prevent loading of the mosfet the output frequency has its connection to the mosfet via a resistor. The AC current, which is generated by the two mosfets behaves like two electronic switches. The current from the battery is enabled to move upper or positive half of the transformer's main coil via Q1. This is done on a situation when Pin 10 gets high and lower or negative half is attained by the opposing current flow via the primary coil of the transformer and when Pin 11 is high. Therefore, the power gets generated by switching the two mosfets.

The AC power is further supplied to step-up the transformer's secondary coil from where we receive the higher AC voltage. The Zener diode on the other hand enables bypass the reverse current.

For upgrading this circuit to any range between 100-watt to 500-watt inverter, you don't have to change anything just make sure the wattage of the transformer is rated above the required output wattage and the AH rating is 10 times more than the transformer primary amp rating

Working of the System

CD 4047 is a low power CMOS astable/monostable multivibrator IC. Here it is wired as an astable multivibrator producing two pulse trains of 0.01s which are 180 degrees out of phase at the pins 10 and 11 of the IC. Pin 10 is connected to the gate of Q1 and pin 11 is connected to the gate of Q2. Resistors R3 and R4 prevents the loading of the IC by the respective MOSFETs. When pin 10 is high Q1 conducts and current flows through the upper half of the transformer primary which accounts for the positive half of the output AC voltage. When pin 11 is high Q2 conducts and current flows through the lower half of the transformer primary in opposite direction and it accounts for the negative half of the output AC voltage.

Working of the solar powered system

Solar energy is one of the major renewable energy resources that can be used for different applications, such as solar power generation, solar water heaters, solar calculators, solar chargers, solar lamps, and so on. There are various advantages of solar energy usage in electric power generation including low pollution, cost-effective power generation (neglecting installation cost), maintenance free power system, etc. Solar power system consists of three major blocks namely solar panels, solar photovoltaic cells, and batteries for storing energy. The electrical energy (DC power) generated using solar panels can be stored in batteries or can be used for supplying DC loads or can be used for inverter to feed AC loads.

Solar Panels' Working Principle

A solar panel is made up of solar cells or solar photovoltaic cells, and is used for converting solar energy into electrical energy. The solar panels utilize Ohmic material for interconnections and external terminals. Thus, the electrons produced in the N-type material are passed to the battery through electrode and wire. From the battery, electrons reach p-type material, where these electrons and holes are combined. Hence, the solar panel connected to the battery behaves like another battery, and hence, is comparable to the two serially connected batteries.

The solar panel output is electric power and is measured in terms of Watts or Kilo watts. These solar panels are designed with different output ratings like 5 watts, 10 watts, 20 watts, 100 watts etc. So, based on the requirement of output power, we can choose appropriate solar panel.

But, in fact, the solar panels output is affected by number of factors like climate, panel orientation to the sun, sun light intensity, the presence of sunlight duration, and so on. During normal sunlight a 12 volt 15 watts solar panel produces around 1 Ampere current. Generally, solar panels maintained properly will work for 25 years. It is essential for designing the solar panel arrangement on the roof top for efficient usage and typically solar panels are arranged such that they face the East at an angle of 45 degree.

Solar Photovoltaic Cells Working

We must also know the working of the solar cells to understand how the solar panels convert solar energy into electrical energy. Solar cells or solar photovoltaic cells are the devices that are used for converting solar energy into electrical energy by utilizing the photovoltaic effect. These cells are used in many real-time applications such as railway signalling systems, street lighting systems, domestic lighting systems, and remote telecommunication systems.

Solar photovoltaic cell consists of a P-type of silicon layer that is placed in contact with an N-type silicon layer. The electrons diffuse from the N-type material to the P-type material. The holes in the P-type material accept the electrons but there are more electrons in the N-type material. So, with the influence of the solar energy, these electrons in the N-type material moves from N-type to P-type.

Thus, these electrons and holes combine in the P-N junction. Due, to this combination a charge on either side of the P-N junction is created and this charge creates an electric field. This formation of electric field results in developing a diode like system that promotes the charge flow. This is called as drift current and the diffusion of electrons and holes is balanced by drift current. This drift current occurs in an area where mobile charge carriers are lacking and is called as the depletion zone or space charge region. Thus, during night time or in the darkness, these solar photovoltaic cells behave like reverse bias diodes.

Generally solar panel open circuit voltage (voltage when battery is not connected) is higher than solar panel rated voltage. For example, consider a 12 volt solar panel giving an output voltage of around 20 volts in bright sun light- but, whenever a battery is connected to the solar panel, then the voltage drops to 14-15 volts. Solar cells are made of most frequently used semiconductor materials such as silicon.

Solar photovoltaic (SPV) effect is a process to convert solar energy into DC electricity using an array of solar panels. This, DC electricity can be stored in batteries shown in the figure or can be used to feed DC loads directly or can be used to feed AC loads using an inverter that turns DC electricity into 120-volt AC electricity.

Working of the Solar Tracking System

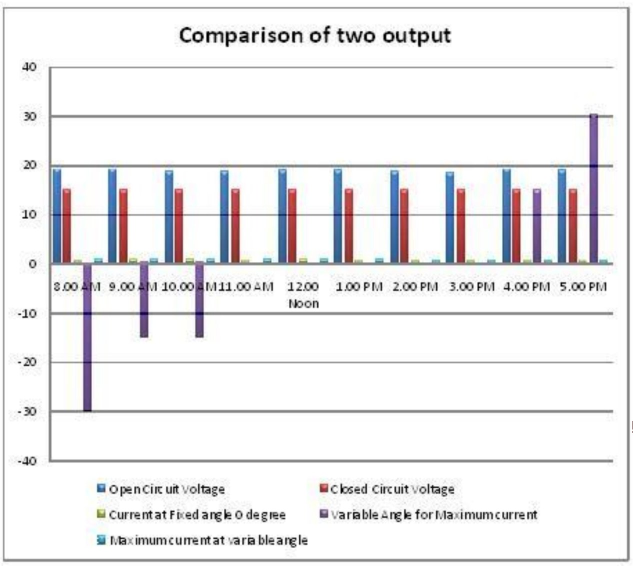
The project uses a motor with a very low speed (10 RPM) to rotate the solar panel along one axis. The direction of rotation is determined by the LRDs which is placed at both ends of the solar panel along the axis. Among 2 LDR's, whichever detects more light, the motor starts rotating in that direction until both LDR receive same amount of light, which utilize the maximum solar energy through the solar panel.

The figure depicts the notion for the instalment of the light dependent resistors (LDR). A secure state is attained when the light intensities of the two LDR become the same. The principal source of light energy, the Sun, moves from east to west. This movement of the Sun causes the variation in the level of light intensities falling on the two LDRs. The designed algorithm compares the variation in the light intensities inside the microcontroller and the motor then is operated to rotate the solar panel, so it moves aligned with the trail of the light source.

Result and Discussion

The project incorporates a motor with a low speed of 10 RPM to rotate the solar panel along a single axis. The direction of rotation is determined by two Light Dependent Resistors (LDRs) positioned at opposite ends of the solar panel along the axis. Whichever LDR detects more light initiates the motor to rotate in that direction until both LDRs receive equal amounts of light, thus optimizing solar energy capture through the panel.

The diagram illustrates the placement of the Light Dependent Resistors (LDRs). A balanced state is achieved when both LDRs detect the same intensity of light. As the primary light source, the Sun moves from east to west, resulting in varying light intensities on the



two LDRs. The programmed algorithm within the microcontroller monitors these variations in light intensity and adjusts the motor accordingly to align the solar panel with the path of the light source.

Calculated Output

Here we have used DC geared motor of 4 R.P.M, 12 Vdc, to rotate the solar panel from east to west and reverse direction. The circuit takes 24mA at 12 Vdc. So, the required Power= 24mA*12V = 288mW/sec. For 6 sec., The required power=288*6=1728mW=1.8W. In a day the panel (or we can say motor) moves east to west and back to east. For 4 rotations the motor takes 1 min/ 60 sec. Therefore, for 1 rotation (360 degree) the motor takes (60/4) =15 sec. To rotate from east to west (180 degree) the motor takes 7.5 sec. So, for 10-degree displacement it takes (3000ms*10degree) /180degree= 167msec. In general, the moves from east to west, i.e. 180degree in 12 hours (6am to 6pm) or 720mins. For 4-degree displacement, the sun takes 720/180= 40 mins. So, in 2 hrs the sun travels 30degree. To cover this 30degree displacement the panel takes (67*3) msec= 201msec.

IV. CONCLUSION

The objective of this project was to develop a dual-axis tracking system capable of sensing incident solar light on the panel and adjusting its position to maximize solar light exposure. The tracking controller is implemented using the ATmega328p microcontroller, with software developed using the Arduino Uno IDE. LDRs (Light Dependent Resistors) are employed to measure solar light intensity, while an LCD displays the power output from the solar panel. The proposed solar tracking system operates automatically, continuously tracking sunlight.

Key conclusions drawn from this study include:

The proposed system offers a low-cost and compact solution compared to existing tracking systems for similar applications.

Its Arduino-based design simplifies programming and modification, eliminating the need for an external programmer.

The automated system enhances panel efficiency, as evidenced by the displayed power output on the LCD.

By reducing reflection on the solar panel, the system increases the efficiency of solar energy generation.

While solar trackers may entail slightly higher costs due to their more complex technology and moving parts, they yield greater electricity generation within a comparable land area to fixed tilt systems, making them advantageous for optimizing land usage.

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