LOW COST SOLAR TRACKING SYSTEM IN WESTERN AMAZON

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ABSTRACT

This paper aims to describe the development of a solar tracking system in the western Amazon, which use some materials collected from wasted copy machines, which lowers cost and helps to reduce the ecological problems, not only through the support of a system of clean energy generation, but also the recycling of old electrical parts of machinery, which most often is a major source of environmental pollution. Solar energy is a very promising alternative source, which is generated by photovoltaic panels that transform the energy captured from the sun. Typically the panels are stationary, but the arrangement reduces that production of energy and the efficiency falls when the angles is different from ninety degrees. The application of the solar tracking system included the development of an embedded system that controls the movement of the solar panel. The solar tracking system moves in both polar and azimuthal axis, in order to put the photovoltaic in such way that it receives sunlight at a perpendicular angle. It uses four LDRs to detect the position of the sun, a stepping motor and a DC motor to move the solar panel according to the position of the sun thereby increasing the efficiency of this method of electrical energy production, being possible to meet the needs of a larger number of consumer society as a whole.

Keywords—*Solar tracking system, photovoltaic energy, microcontroller, embedded system, alternative energy source.*

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I. INTRODUCTION

The solar panels are usually stationary thus making that the incidence angle of the sunlight varies throughout daytime. Studies show that the efficiency of a solar panel is lessened when the incidence angle is other than ninety degrees [1].

The solar tracking system elaborated in this paper is an hardware with two degrees of freedom, polar and azimuthal axis, that allows a solar panel to always receive sunlight in a perpendicular way. This is possible thanks to an embedded system that perceives the angle variation during the day and moves the solar panel.

The sunlight incidence angle constantly varies, not only during the daytime, but it also changes severely during the different seasons of the year. Moving the solar panel in order to track the sun can significantly improve the energy output.

A solar tracking system is an equipment that orientates a photovoltaic panel in such way that they are always facing the sun, improving the sunlight incidence on their surface [2].

The conversion of sunlight in electric energy is one of the most promising and challenging technologies, which is in constant development. Solar energy is clean, silent and reliable, with low maintenance costs and minimum ecological harm. It is free, virtually inexhaustible and does not contributes to pollution [3].

Solar tracking systems are massively used in many other countries with significant improvements in the energy production, yet, there wasn't any research on that matter at Rondônia, in Brazil's North region.

II. PHOTOVOLTAICS

The energy generated by the sun can be used both as a source of heat as light, is now, without doubt, one of the most promising energy alternatives to meet the challenges of the new millennium [4].

Photovoltaic Solar Energy is the energy obtained by direct conversion of light into electricity. The base device for converting light into electrical energy is the photovoltaic cell which directly converts solar energy into electricity through the photoelectric effect [5].

The photovoltaic effect, defined by Edmond Becquerel in 1839, is the appearance of a potential difference produced by light absorption at the ends of a structure of semiconductor material [6].

Photovoltaic (PV) cells comprise a semiconductor material in which the most used element is silicon, which are said doping substances added in order to create a suitable means for establishing the photovoltaic effect, i.e. direct conversion of power associated the solar radiation into DC electrical potential.

III. TAXONOMY OF SOLAR TRACKING SYSTEMS

There are many models of solar tracking systems and they can be classified in several categories considering their degrees of freedom, the kind of the structure, the tracking strategy and the control system. In figure 1 is shown as are classified the solar trackers.

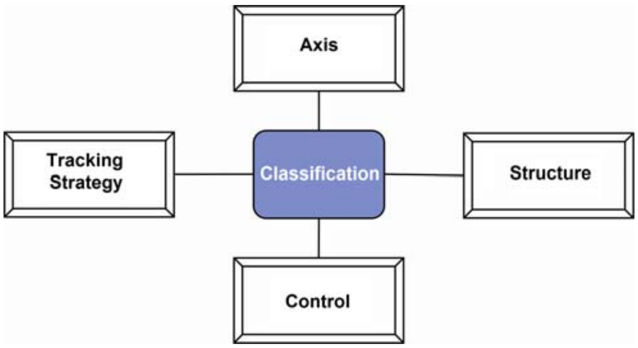

Figure 1: Classification of solar followers in function parameters.

The most common solar trackers are the single axis solar tracking systems due low operational and building costs. Their tracking strategy can be polar, figure 3, moving the solar panel on the North-South axis, azimuthal, figure 2, which uses a motor on the vertical axis, following the sun in the East-West axis, having a good performance in latitudes and seasons where the days are longer, or horizontal, a simpler build used in places near the equator in figure 4 is shown the horizontal type.

Figure 2: Single axis azimuthal solar tracker.

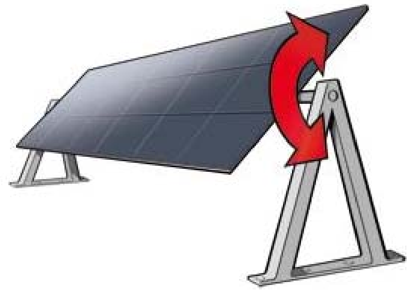

Figure 3: Single axis polar solar tracker.

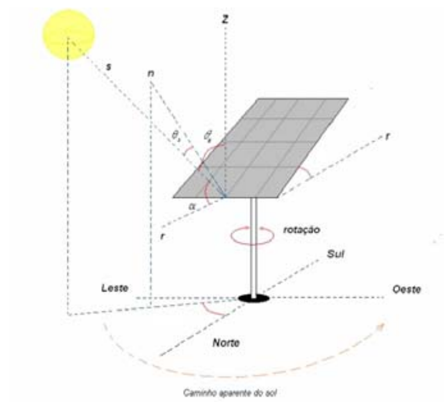

Figure 4: Single axis horizontal solar tracker.

The double axis solar tracking systems are more complex they have polar and azimuthal, which has a better performance and improved precision, although it has greater building costs. They can be either polar/equatorial or azimuthal/elevation.

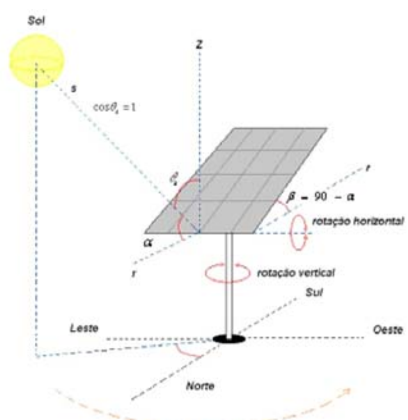

Figure 5: Double axis tracking system's degrees of freedom.

Figure 6: Double axis tracking system.

Their control system can be a passive one, which does not use motors and have low precision, optic-electric which have good results but can lost the track in cloudy days, and the systems based upon microprocessors, that have precision and adaptability.

IV. MECHANICAL SYSTEM

The mechanical structure of the solar tracking system azimuthal axis is based in a three gears transmission which was taken from an old wasted copy machine. The first spur gear has 18 teeth is rotated by the stepper. The second one has 50 teeth.

Picture 7: The solar tracking system transmission.

This coupling transmits the rotation to an axis which is held by an axial and radial bearing with an inner diameter of 25mm. This arrangement supports an iron round plate which has a 35cm diameter. Over this plate there is the DC motor, attached to a 25cm long worm drive, which moves at 1.27cm/s rate and is responsible for moving the solar panel in the polar axis. The solar panel is attached to a structure that resembles an U. All this structure is attached to a semi-pyramidal base.

V. SOLAR TRACKING SYSTEM

The operation of the solar tracking system is based upon a solar position sensor. This sensor is constituted of four 10mm light dependent resistors (LDRs) placed in a cross shape over a cylindrical support and shielded from sunlight by a small round plate which is 2.5cm away from the four LDRs, in such way that if the light comes in an orthogonal angle the LDRs are completely shadowed. However, if the light comes from a slightly different angle, one of the LDRs will get more light than the others and his electrical resistance will decrease.

A light dependent resistor (LDR) is constituted of two cadmium sulfide photoconductive cells, which electrical resistance falls with increasing light intensity [7].

Each of the LDRs is electrically connected in series with a 100Ω resistor, creating a voltage divider. The voltage drop in each of the four resistors is read by an analog pin of the microcontroller, which will compare the readings and test if any of the LDR's are getting more light than the others. The four voltage dividers are configured to work in pairs: a pair of LDRs perceives the polar angle and the other measures the azimuthal light incidence angle, so the system can track the sun in those two degrees of freedom.

The tracking system will dynamically adjust its position whenever one of the LDRs perceives a significant change in light intensity, due an alteration of the sunlight incidence angle, thus making one of the LDRs not being shadowed anymore by the round plate. This configuration makes the solar panel, which starts the day facing the east, end up facing west, by the evening. The code uploaded to the microcontroller keeps monitoring the four voltage drops. If in a given moment any of those increases by more than a threshold level of 185mV that means a LDR is receiving more light than his pair, then the microcontroller will activate the DC motor, if the LDR which is sensing more light is in the polar axis, or the stepper, whether the LDR is in the azimuthal axis, until both LDRs are getting the same light intensity again, so the voltage drop in their resistors is the same, which means that the sensor and the solar panel are receiving sunlight in ninety degrees.

In order to move the solar panel on the polar axis the solar tracking system uses a 24V 0.3A DC motor which will rotate the worm drive to lift or lower the solar panel. This DC motor was collected from a wasted copy machine. To drive this motor, the system uses a h-bridge constituted of four TIP120 darlington transistors, four 1N4007 rectifier silicon diodes and four 10kΩ resistors. In figure 8 is shown the circuit to drive the DC motor.

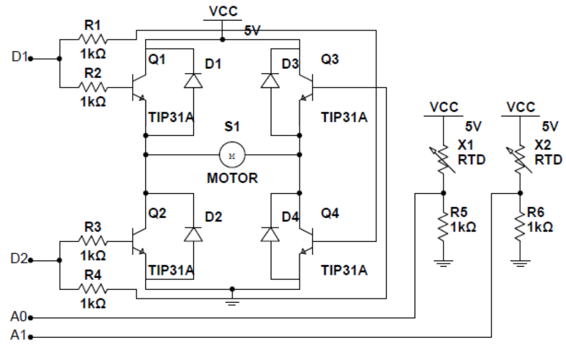

Figure 8: H-bridge schematic.

A darlington transistor configuration is the cascade association of transistors, where the base current of the second transistor comes directly from the first one's emitter and the current gain is the product of the two gains [8].

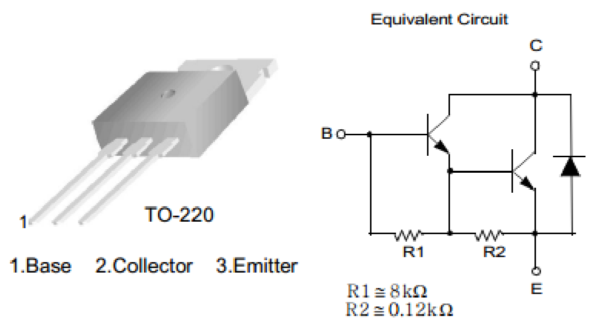

Figure 9: TIP120 npn darlington transistor.

The h-bridge is a circuit usually used to control de direction a motor is rotating, as this circuit allows to change the way the current goes through an element, which is very convenient, because the way the shaft of the motor turns is determined by how the motor is polarized.

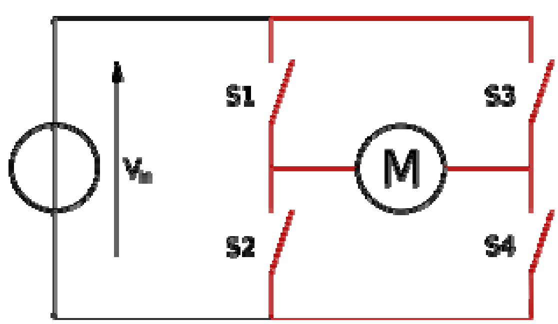

Figure 10: The basic h-bridge.

The basic h-bridge is composed by four switches placed in such way that they look like an "H", where each switch is on an end of the "H" and the motor is in the middle of it. To get the motor working is necessary to activate a diagonally opposed pair of switches, so the current will flow through the motor. If the first pair is deactivated and other pair is activated the motor will turn the other way. If the two upper switches or the two lower switches are activated at the same time the motor will stop immediately, as both terminals have the same voltage [9].

In the solar tracking system h-bridge there are four TIP120 npn darlington transistors, which are used as switches. The TIP120 is indicated for medium power linear switching applications, its maximum V_{CEO} is 60V and its maximum collector current is 5A, fitting well in the 24V 0.3A DC motor driver circuit [10].

A digital pin of the microcontroller will activate a pair of transistors sending, through a 10kΩ resistor, a current of approximately 0.43mA to the base of each transistor, thus enabling the DC motor to run.

The 1N4007 diode, placed in parallel with the transistor is there to prevent back EMF. When the magnetic field of the motor coils collapses, this collapsing field can produce a reverse voltage that could damage the circuit [11].

Given this configuration, when the sensor perceives any change in the polar angle of the sunlight incidence the microcontroller will send current to two diagonally opposed transistors, in such way that the current flow through the DC motor and then lifting or lowering the solar panel until it is at ninety degrees to the sun again.

To move the solar panel in the azimuthal axis the solar tracking system uses a M55SP stepper motor, which was taken from an old broken printer machine.

A stepper motor is a brushless synchronous electric motor which moves a step at a time, in others words it moves a discrete angle at a time, what makes it a very precise and easily controllable motor, as every complete revolution is divided into a discrete number of steps. In fact, most of the times feedback is not even needed, as far as knowing the stepper position is just a matter of counting steps. They also have good repeatability of movement since they have high accuracy and any error is non-cumulative from one step to another. These characteristics elect steppers as the best choice in positioning applications. They also have a good torque at lower speeds [12].

A stepper is composed of stators, which are stationary, the windings, which are wrapped around the stators and the rotor, the rotating component of the stepper. When the current flows through the windings they create polarity at the ends of the stators, and the magnetic flux will pass through the rotor thus making it rotate to minimize the flux path [13].

There are two usual ways to drive a stepper motor, being those the full step and the half step. The full step is the simplest configuration as the driver just sends a pulse to each winding, two of them being activated at a time. The half step configuration activates alternately one and then two windings. That makes the shaft of the motor rotate half step to each pulse, what doubles the number of steps, increasing the angle resolution.

The M55SP is a unipolar 4 phase compact high precision stepping motor, collected from an old copy machine, which has and high torque output, a 7.5° step angle, and good stability. It operates at 24V and 216mA. There are 4 winding wires and two common wires. A winding will be energized when a current flows through its wire and its common [14].

To drive the M55SP the solar tracking system uses four TIP120 darlington transistors and four 10kΩ resistors. The transistors are connected in the common-emitter configuration as shown at the schematic in the figure 11, with a winding wire connected to the collector and a digital pin of the microcontroller connected through a resistor to the base. Both the common wires of the stepper are connected to the battery. Whenever the light sensor perceives a significant change in the sunlight incidence at the azimuthal axis the microcontroller will send pulses to the base of the transistors in a half step configuration thus making the solar panel rotate until it is receiving sunlight orthogonally again.

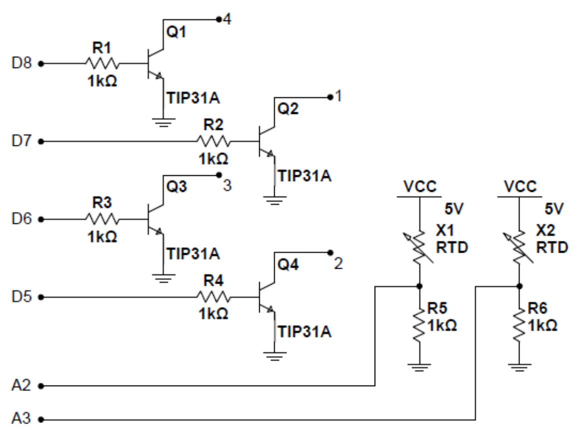

Figure 11: Stepper driver and light sensors.

In order to control all the motors and process the input of the sensors, the solar tracking system uses a microcontroller. The chosen microcontroller was Atmel's ATmega328, a high performance 8-bits AVR RISC-based microcontroller, which can execute complex instructions in a single clock cycle. It has 32kb ISP flash memory,1kb EEPROM, 23 general purpose I/O lines, 32 general purpose working registers, internal and external interrupts and other characteristics that elects this as a very reliable microcontroller.

The solar tracking system is designed to not move in its axis in ways that would exceed the length of the worm drive on the polar axis or rotate to much in the azimuthal axis so it could damage the sensor and motor wires. In order to prevent those occurrences the tracking system uses a pair of form A reed switches to detect if the solar panel has reached its lower or upper limit whenever a magnet placed on the solar panel comes close to the reed switch, and a single form A reed switch that will detect an small magnet placed on the azimuthal main gear when it reaches the west position.

Reed switches are small devices consisting of two ferromagnetic blades, called reeds, hermetically sealed inside a glass envelope. There are form A reed switches which are normally open and form B which are normally closed. A reed switch is operated by a magnetic field, usually generated by a magnet or a current carrying coil. When the field is removed the switch reverts to its previous state [15].

Three digital pins of the microcontroller will read the switches. If at any moment the magnet which is attached to the solar panel comes close enough to the lower or upper polar reed switch the respective digital pin will receive a 5V voltage and the microcontroller will stop the DC motor from keep moving in that direction. If the magnet placed on the gear come close enough to the azimuthal reed switch the microcontroller will recognize that the solar panel is facing west. During daytime the solar panel will rotate clockwise from east to west. At the end of the day, if it is facing west, it is at the lowest polar position and the light intensity perceived by the sensor is low enough, in other words is both the azimuthal and the lower polar reed switches are activated and the voltage drop in all resistors in series with the LDRs are at a level recognized as the one given by lack of daylight, the solar panel will rotate counterclockwise from west to east.

VI. BATTERY CHARGING SYSTEM

The energy produced by the solar panel charge a lead-acid battery through a charger circuit. The charger will be attached to the output of the battery, since the voltage and current generated are able to charge a 12V or 6V. The schematic on the picture 12 shows the circuit which supplies a continuous voltage to the battery. The input voltage pass through the capacitors C1 and C2 which act as filters and go into the LM317 integrated circuit, a linear adjustable voltage regulator. The output voltage is given through the equation:

$$V_{out} = 1.25\left(1 + \frac{R_2}{R_1}\right) \quad (1)$$

When the switch S1 is closed the output will be 6V, if the switch is opened the output will be 12V. The diodes D1 and the D2 prevents damages from wrong polarization of the battery.

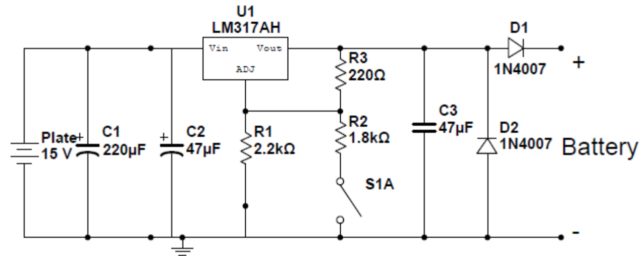

Figure 12: lead-acid battery charger.

VII. DISCUSSION

The solar tracking system presented in this work shows interesting solutions to detect the position of the sun using electronic components as simples as LDRs and resistors and a small protective round plate to shield the LDRs from the sunlight in such way that if one of them is no longer shadowed the system perceives that the sun has moved a significant angle and it is time to reposition the photovoltaic.

The repositioning system and the mechanical structures are quite distinctive in this project because many pieces of they such as the DC motor, the gears, the axis and the stepper motor came from discarded copy machines, what lower the cost of the project, since solar tracking systems with two degrees of freedom are usually expansive. This work also suggested a simple circuit to charge a lead-acid battery with the solar panel voltage output. That said, the objectives were successfully accomplished although there is still a lot of improvements that can be done in the solar tracking system project.

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